ELEMENTARY LESSONS

IN THE

PHYSICS OF AGRICULTURE.

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PREFACE.

Because of the entire lack of literature relating to the physics of agriculture, in any form available for class instruction, these elementary lessons have been undertaken to meet the immediate needs of our Short Course students. They are intended simply as a temporary expedient to be used until time shall permit the preparation of a suitable text-book on the Physics of Agriculture, this field being at present entirely unoccupied.

Farm drainage; the construction, ventilation and warming of farm buildings; physical principles and care of farm machinery; water supply for farms; and the forecasting of weather changes are among the topics presented to our classes, but which could not be outlined in time to be included here.

INTRODUCTORY.

1. Physical and Chemical Changes.— When trees are cut into stove wood or cut into dust with the saw, the pieces which remain are wood still and such changes are *physical;* but when the wood is placed in the stove and burned changes take place which destroy the wood, as such, and these are *chemical changes.* When a lump of sugar is dissolved in water the sugar is sugar still and may be recovered as such by evaporating the water, and the change is a *physical* one; but when yeast and "mother of vinegar" are added to the sweetened water and allowed to stand the sugar is transformed, alcohol and then vinegar appear in its stead, and the changes are *chemical* ones. The fall of rain and snow to the ground, the flowing of streams to the sea and the evaporation and return of the water to the land again are all physical changes. The operations of tillage, of drainage, the cutting and handling of farm produce and the making of butter are physical processes. The running of farm machinery and the construction of farm buildings involve an understanding of *physical* rather than *chemical* laws.

Write a list of five physical and five chemical changes.

2. Matter and Force.— The physical universe, so far as we are able to comprehend it at present, appears to be made up of two classes of agencies, one of which is active and called *force*, while the other is passive, or acted upon, and named *matter.* Water is matter, and gravity is the unseen force or agency which causes it to flow to the sea or to turn the water-wheel; air is matter, but gravity is the force which moves it in the wind when it drives the ship or turns the wind-mill. Wood and oxygen are matter, but chemical affinity is the force which drives their molecules into collision producing the intense heat and light of the fire.

3. Kinds of Matter.— Chemistry at present distinguishes about seventy kinds of matter which are known as elements or elementary substances; oxygen, hydrogen, nitrogen, carbon, iron, sulphur and phosphorus are seven of these. Water is not one of the elements, for it can be decomposed and shown to consist of oxygen and hydrogen. Sugar is not an element, but is made up of carbon, oxygen and hydrogen.

4. Constitution of Matter.— Each and every body or mass of elementary substance, is composed of large numbers of minute units or individuals named *atoms*, which various lines of experiment, observation and reasoning show to be constant in weight and properties, so far as we know them; and it is in consequence of this constancy of weight and properties that chemistry is able to analyze the various substances and tell us their composition.

The atoms of which all bodies are composed rarely exist alone; they are bound into tiny clusters called *molecules*. Some of these molecules are made up of two atoms, like those of common salt containing one of chlorine and one of sodium; other molecules contain three atoms, like those of water, two of hydrogen and one of oxygen; molecules of cane sugar contain forty-five atoms, twelve of carbon, twenty-two of hydrogen and eleven of oxygen. Commercial analine violet possesses molecules of fifty-seven atoms of five different kinds, and there are other atom clusters or molecules more complex than these.

5. The Size of Molecules.— The size of molecules is almost inconceivably minute. Sir William Thompson computes the number of molecules in a cubic inch of any perfect gas having a temperature of 32° F. and under a pressure of thirty inches of mercury, to be 10^{23} or ten sextillions.

We have many strong proofs of the extremely minute size of molecules. If a grain of strychnine be dissolved in one million grains of water, and if we place one grain of the water containing the strychnine in the mouth, its bitter taste is recognizable, and yet the volume of a grain of strychnine is only about $\frac{1}{203}$ of a cubic inch. A cubic inch of analine violet will impart its purple color to more than eight million three hundred and eighty-four thousand cubic feet of water. Nobert succeeded in engraving parallel lines on glass at the rate of more than one hundred thousand to the inch, and hence the point of his diamond must have been much thinner than this, and the diameters of the molecules which composed it smaller still.

The fact that musk and other perfumes keep the air of large apartments so charged with their molecules that we are able to detect them in spite of the fact that the air is constantly changing and the loss in weight of the perfume is extremely small indeed, is still another striking proof of the minuteness of molecules, and, at the same time, of our ability to recognize them.

6. Properties of Atoms.— Atoms, so far as we know them, and are able to deal with them, can neither be created nor destroyed; they have magnitude and weight, but are indivisible and impenetrable.

7. Properties of Molecules.— Molecules possess all the properties of atoms except that they can be both destroyed and created and are divisible into atoms. Whenever a chemical change takes place existing molecules are transformed into new ones of a different kind, and chemistry, as a science, deals with these changes, while physics deals with the molecules and groups of them.

8. Structure of Bodies.— The bodies or masses of matter with which we are familiar are always composed of molecules, but these molecules are believed to be not in contact with one another.

If a quantity of salt be placed in a vessel and then water added so that the combined volume before solution fills the vessel, when the salt dissolves the volume will be found to be less.

The fact that bodies change their volume with changes of pressure and of temperature also indicates that the molecules which compose them are not in contact.

The mercury in a thermometer, for example, fills the bulb at 212° F. and a certain portion of the stem also, but as the temperature falls the mercury in the stem withdraws into the bulb and yet the capacity of the bulb diminishes by contraction at the same time, and this could not take place were there not room in the bulb not occupied by the molecules of mercury.

9. Molecules of Bodies Not at Rest.— Not only are the molecules which constitute the various bodies around us not in contact with one another, but a large number of facts and observations indicate that they are not relatively at rest. If a solution of sugar or salt be placed in the bottom of a vessel and covered with water the molecules of sugar and salt travel upward and those of the water downward until, finally, a uniform mixture of the two liquids has resulted. The same fact is also observed where two gases are brought in contact — diffusion takes place. So, if a solid lump of sugar or of salt be placed in water, the molecules travel away and disperse themselves through the whole mass. The molecules of fragrance from fruits and flowers are constantly traveling away from their respective places of origin. Molecules of camphor leave the solid lump and travel through the surrounding air, and snow disappears into the atmosphere without melting on the coldest of winter days.

The pressure which steam exerts upon the head of the piston when driving the engine is regarded as due to the collision of the molecules against its face; and the pressure exerted by all gases is explained in the same way. The temperature of bodies is also an expression of the degree of molecular agitation within them. When we place the fingers upon a warm body the motion of its molecules is communicated to the molecules of the cuticle, and this in turn to the nerve endings, and onward through the nerves to the nerve centers in the brain, giving rise to the sensations denominated hot, warm, cool or cold.

The mean distance traveled without collision by a molecule of hydrogen at ordinary temperature and pressure is computed by Crooks at $\frac{1}{10000}$ mm., or $\frac{1}{254000}$ in., while the velocity is at the rate of about six thousand feet per second. The heavier the molecules are the slower they move, the rates being inversely as the square roots of their weights. Thus the oxygen molecule, being sixteen times as heavy as the hydrogen molecule, moves, under like conditions, only one-fourth as rapidly.

If it is difficult to think of a body like a horse-shoe or a hammer maintaining its form when its molecules are neither in contact nor relatively at rest, it may be helpful to turn to the solar system, consisting of the sun, planets, satellites and asteroids, together with comets and meteors, all of which are in constant and rapid motion, separated by immense distances, and yet as a whole constituting one great body, maintaining a definite form and size as it travels through space.

10. Kinds of Force.— The falling of leaves, of rain-drops and of unsupported bodies generally, is a constant reminder of an influence which the earth, as a whole, exerts upon bodies at its surface. The strength and rigidity of solids as compared with fluids; the union of two boards by means of glue; the rise of oil in a lamp-wick, and its destruction by burning, with the appearance of heat and light, all convince us of influences of some sort which the molecules of bodies exert upon one another.

It has been customary to speak of these influences as due to the action of different kinds of force, and they have received distinctive names.

11. Gravitation is the action which any one molecule exerts upon every other molecule, tending to draw them together no matter how great the distance may be between them. The intensity of this attraction is directly proportional to the mass and inversely proportional to the distance between the molecules.

The weight of a load of hay or of a bushel of wheat is the sum of the attractions of every molecule of the earth upon all the molecules of the load of hay or bushel of wheat.

12. Molecular Forces.— When molecules are brought very close to one another, so that the distances between them become inappreciable, their tendency to come together or their resistance to separation are spoken of as due to molecular attraction, and three varieties are designated, viz., cohesion, adhesion and chemical affinity.

13. Cohesion.— When water is cooled below 32° F. the rate of molecular motion and the mean distance between the molecules so diminishes that the force of *cohesion* begins to bring them into new relations and to bind them more firmly together, so that a solid body results. The same force comes strongly into action when melted iron, copper or other metal changes from a liquid to a solid state.

When finely ground graphite is subjected to extreme pressure in moulds, after having been first thoroughly cleaned, the molecules of the separate fragments are brought so closely together that they unite into solid cakes, from which the leads of pencils are sawed. Where molecules of the same kind are thus bound together the acting force is named *cohesion*.

14. Adhesion.— When the smooth, plane surfaces of two pieces of wood are coated with a paste of glue and brought firmly together they are held very securely when dry. In this case the action between the molecules of glue and the molecules of wood on either side serves to make a single body of the three. The action seems to be essentially the same as that of cohesion, but because it occurs between molecules of different kinds the term *adhesion* is used to designate this distinction. The coating of walls with white-wash, paint, varnish and the like are other manifestations of the same force.

15. Chemical Affinity.— When the temperature of wood is raised to a sufficiently high point in the presence of air an action occurs between the molecules of wood and those of the oxygen of the air, which results in the complete breaking down of both sets of molecules and the formation of new ones of entirely different kinds in their stead. This sort of molecular action, as in the case of adhesion and cohesion, takes place only across insensible distances, and the agency which brings it about is named the force of *chemical affinity*. The rusting of iron, the heating of a manure pile or of a silo, the souring of milk and the processes of digestion are all phenomena in which this force is operating to form new molecules from old ones.

16. States of Substances.— It is common to speak of substances as existing, under different conditions, in a solid, liquid or gaseous state. A critical study of these states, however, shows that no absolute distinction exists between them, and that, by insensible gradations, one state may shade into another. The substance water we know as solid ice, liquid water and gaseous steam. Iron at ordinary temperatures we think of as a solid, but as its temperature is raised it gradually becomes more and more soft until it passes by insensible shades into the condition of a true liquid.

The *ideal solid* is a body which, if brought under a force which tends to change its form, responds, if at all, to the force, and then remains unchanged so long as that condition of stress may exist. The steel spring, when loaded, changes its form, and then remains constant until the load is removed, or rather appears to when rough measurements only are applied as a test; but if more than a certain load is applied, the form keeps changing so long as the load acts.

The *ideal liquid* is the body which constantly changes its form whenever a force is made to act more intensely upon one portion of it than upon another. We think of water as a perfect fluid, and yet a comparatively heavy load may be placed upon a drop of water resting upon a dusty surface without its changing form, except a definite amount at first. On the other hand, we think of sealing-wax as a solid, and yet if a bullet be placed upon it, it will, by its own weight, gradually sink through it. But jelly, even when rather soft, will keep its form under the same load which will sink through the sealing-wax: the sealing-wax conforms to the law of liquids and the jelly to that of solids.

In the gaseous state the molecules of the substance have attained so large a range of motion that the molecular attractions appear entirely overcome, and the molecules continually separate from one another unless some confining surface or wall prevents them. No vessel can be half filled with a gas as it can with a solid or a liquid, for the molecules travel to and fro from side to side or from top to bottom, thus occupying the whole space, no matter whether the number of molecules be ten or ten millions.

17. Work.— When a force, like that exerted by a horse, acts upon a quantity of matter and changes its position in any direction, *work* is done, and the amount of it is measured by the product of the force and the space through which the mass has been moved.

Work=Force x Space.

If a horse exerts an average tension of twenty pounds through the whippletree upon the carriage and moves it through ten thousand feet the work done is

20 lbs. x 10,000=200,000 foot-pounds,

meaning the equivalent of two hundred thousand pounds lifted one foot in opposition to gravity.

So if the horse exerts a tension of one hundred pounds in raising a forkful of hay and carries it through a height of forty feet the work done is

100 lbs. x 40=400 ft.-lbs.

Simple pressure is not work. The load must move before work is done. The man who stands still under a sack of grain does no work on the load he holds.

The mean rate of doing work is the whole work done divided by the time required to do it, and 550 foot-pounds per second is called a Horse-power by Engineers. This, however, is more work than the average horse can do, this being estimated by General Morin at 26,150 foot-pounds per minute or 435.8 foot-pounds per second.

A laborer lifting dirt with a spade has been found able to do 470 foot-pounds per minute, and on a tread power, raising his own weight, 4,230 foot-pounds per minute; the first being .018 of an animal horse-power and the latter .16 or a little less than one-sixth.

18. Energy.— Energy is the ability of a moving body to do work. If a twenty-pound weight, suspended by a cord, be drawn to one side and then allowed to fall, it will rise on the opposite side of the line of rest to a height nearly equal to that from which it fell. This height would exactly equal that from which it falls if the air and the suspending cord offered no resistance. Here the moving weight, on reaching its lowest level, has acquired an amount of energy equal to that which has been expended in raising the weight to the point from which it fell.

When a hammer is brought to rest on the head of a nail it is the energy of the moving hammer which does the work of forcing the nail into the wood.

The wind blowing through the wind-mill has its velocity reduced, and so much of its energy is transformed into motion of revolution in the wheel. The same is true of water in flowing through a water-wheel, the water loses energy by imparting it to the wheel.

When the spring of a clock or watch is wound up its molecules are drawn out of positions of rest, as with the weight referred to, and in falling back to their positions of rest again their energy is imparted to the train of wheels to which the spring is attached.

19. Energy and Matter Indestructible.— No discovery of modern science is more fundamental and far-reaching than that of the indestructibility of both matter and energy, and equally fundamental is the other fact that neither of them can be created.

One form of energy can be transformed into another form and one kind of substance can be decomposed and others made from the components, but in these transformations there is never either annihilation or creation. The few bushels of ashes left from the winter's supply of coal or wood seem to point to a destruction of matter, but their weight added to the weight of the products which escaped through the chimney is actually greater than that of the original fuel, for oxygen from the air has united with it. So when the energy of eight or ten horses is being expended in the threshing of grain it looks as though energy were being annihilated, but it is simply changed into heat, sound and energy of position, not lost. We appear to realize in the waste products of domestic animals and the increase of their bodies a very much smaller weight of matter than they have consumed, but this is because so large a weight passes off in an invisible form through the skin and lungs. *Something is never*, so far as we know, reduced to *nothing;* neither is *something* created from *nothing.*

20. Machines Not Generators of Energy.— When, through the aid of a machine, a man or a horse is able to move a load which he could not otherwise handle, the machine is not a source of energy, it is simply a device which enables their energy to be transmitted and used more advantageously; but there is always some loss in the machine, no matter what that machine may be. Some energy is required to overcome the necessary friction of the moving parts of the machine so that the useful work accomplished never quite equals the energy expended.

21. Inertia of Matter.— Newton's first law of motion may be stated as follows: *Every body tends to persevere in its state of rest or of uniform motion in a straight line unless acted upon by some external force*, or briefly, *matter has inertia.* There are many unmistakable illustrations of this law. The sudden starting of a wagon tends to throw a standing person backward because his feet take on the motion first and are carried out from under him. In beating a carpet the carpet is driven forward away from the dust. In driving a nail the suddenness of the blow forces the wood aside and in front of the nail before the motion can spread to the surrounding wood.

When a horse, in rapid motion, suddenly turns a corner, the rider must lean in the direction of turning until his tendency to fall exactly balances his tendency to move on in a straight line. It is the principle of inertia which enables the rider to sit securely on the bicycle while it is in motion; the same principle explains the standing of the top while in motion, and the constant parallelism of the earth's axis during its revolution about the sun. The rider on the bicycle is moving rapidly in one direction, and for him to fall either to the right or the left would require him to change his direction of motion at a right angle, which is the same thing as trying to turn a corner when at full speed — a thing practicably impossible. It is this law of inertia which makes it possible for the penman to make his smooth curves only by rapid movements of the hand.

22. Centrifugal Force.— Centrifugal force, so called, is another manifestation of the law of inertia. The stone twirled about the head with a string, because of its tendency to move always in a straight line, exerts a constant tension upon the string, and if the rate of motion is great enough the string will be broken.

It is this manifestation of inertia in circular motion which lies at the foundation of all rotary forms of cream-separators and extractors and of several forms of fat-tests for milk.

In the Babcock and Beimling "milk-tests" the rapid revolution of the bottles which contain the fat to be separated from the liquid with which it is mixed, throws the heavy liquid to the bottom of the bottles, which reacts upon the fat, forcing it toward the center of the circle, where the velocity is least. The fat, like the heavier liquid, in consequence of its own inertia, tends to go to the bottom of the bottles also and is simply prevented from doing so by the greater inertia of the heavier liquid.

23. The Gravity Method of Creaming.— To understand the reason of the more rapid and perfect separation of cream by the centrifugal methods over the simple gravity methods we need to get first the principle of creaming by gravity.

It is this: If a block whose weight is but one-half that of an equal volume of water be immersed in water it will be lifted by a force equal to the difference between the weight of the block and that of an equal volume of water, as shown in Fig. 1.

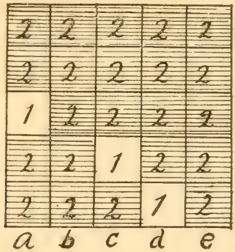


Fig. 1.

Regarding the water of the vessel divided into cubes exactly equal in volume to the block of wood, and the block just half as heavy as an equal volume of water, then the weight of column A equals

$$2+2+1=5,$$

while the weight of column B is

$$2+2+2=6.$$

Now, as column B exerts a pressure upward on the column A equal to its own weight, the block in column A must be pushed upward by a force equal to the difference in the weight of the two columns, or of

$$6-5=1.$$

A comparison of columns B and C will show that it makes no difference where the block is placed in the liquid, the force which tends to lift it to the surface is always the same. If the attraction of the earth were just twice as strong as it is then the cubes of water and the block in column A would weigh

$$4+4+2=10,$$

and the cubes of water in column B would weigh

$$4+4+4=12,$$

and the lifting force on the block would be

$$12-10=2,$$

or just twice what it now is; so if the force of gravity were made one hundred times what it now is, the lifting force acting upon the immersed block would be increased one hundred fold.

24. Centrifugal Creaming.— The centrifugal methods of creaming are applications of the same principle as the gravity methods, the only difference being in the substitution of a stronger force in the place of gravity, and by so doing of shortening the time and securing a more complete separation. This is done by transforming the energy of an engine or of some other form of motion into the energy of rapid rotation in the milk, giving rise to a strong outward pressure, which acts exactly as gravity does in the old method of creaming.

25. To Compute the Centrifugal Force.— The strength of centrifugal force in a milk separator may be computed as follows:

$$\text{Centrifugal Force} = \frac{\text{weight of milk x (velocity in feet per sec.)}^2}{\text{radius x 32.2.}}$$

Suppose the mean diameter of the circle through which one pound of milk is made to revolve is ten inches and that the centrifuge is given seven thousand revolutions per minute. In this case the

$$\text{Velocity} = \frac{10 \times 3.1416 \times 7000}{12 \times 60} = 305.4,$$

$$\text{then centrifugal force} = \frac{1 \text{ lb.} \times (305.4)^2}{\frac{5}{12} \times 32.2} = 6950,$$

and this means that the creaming force would be six thousand nine hundred and fifty times as great as by the old gravity method.

26. Strength of the Creaming Force.— Since the mean specific gravity of milk fat at 85° to 90° F. is about .91 and that of milk serum 1.034, the creaming force must be the difference between the two specific gravities, as shown in **23**, or

$$1.034 - .91 = .124;$$

that is, if a ball of butter-fat weighing .91 pounds were placed in milk serum, the lifting force of gravity upon it would be .124 pounds, but if placed in milk serum in the centrifuge under the conditions of **25** the creaming force would be

$$6950 \times .124 = 861.8 \text{ lbs.}$$

This enormous creaming force seems unnecessarily large, and so it would be if the fat globules were large enough to weigh .91 of a pound each, as in the problem assumed, for then creaming by the gravity method would be practically instantaneous, whereas, under existing conditions, it requires about twelve hours.

The actual diameter of the average fat globule in milk is not far from $\frac{1}{5000}$ of an inch, while a sphere of butter-fat weighing one pound would have a diameter of about 3.87 inches.

Now as the volumes of spheres are to each other as the cubes of their diameters, the pound of fat should contain about seven trillion two hundred and forty-five billion of fat globules. But the surfaces of spheres are to each other as the squares of their diameters, and hence the surface of the pound sphere will contain the surface of the fat globule about three hundred and seventy-four million four hundred and twenty-two thousand five hundred times; and this being true, the aggregate surface of the seven trillion two hundred and forty-five billion fat globules, whose aggregate volume equals that of the pound sphere, must be

$$\frac{7245000000000}{374422500}=19,350$$

times the surface of the pound sphere; and when we remember that the friction increases with the surface, and that more force is required for rapid creaming than for slow, we can see that a much stronger creaming force is really needed.

27. Storing Energy.—In many forms of machinery where the work to be done, like that of sawing wood with a buzz saw, is not a steady draught upon the source of power, a fly-wheel, or its equivalent, is very useful in allowing the power generator to store energy when work is not being done and give it out again as needed. The wind-mill in pumping water, with most pumps, does work only half the time, and so there is often attached to the pump an air-chamber which acts like a spring in which the mill stores energy by compressing air which is given out during the reverse stroke. A constant stream is thus maintained and the pump enabled to be worked with lighter winds than would otherwise be possible.

In the animal mechanism the walls of the arteries are elastic and act like springs. They are stretched by the powerful, quick contractions of the heart, and then, while the heart is resting, the blood is forced on by the steady return of the stretched arterial walls, and continuous currents of blood are thus moving through the tissues of the body.

28. Momentum.— When a body weighing ten is moving with a velocity of ten, the quantity of motion is

$$10 \times 10 = 100,$$

and this is called its *momentum.* If the mass of the body is one thousand and its velocity is five, then

$$1{,}000 \times 5 = 5{,}000,$$

the quantity of motion, or momentum, of that body. So a body having a mass of five and a velocity of one hundred has the same momentum as a body weighing ten, having a velocity of fifty, for

$$5 \times 100 = 500 \text{ and } 50 \times 10 = 500.$$

ELEMENTS OF MACHINES.

29. The Mechanical Powers. — The simple machines known by the names *lever, wheel and axle, inclined plane, screw, wedge and knee* find an explanation of their action in the fact that they simply transmit motion with an altered velocity or direction, the quantity remaining always the same, except as it is diminished more or less by the friction and weight of the parts of the machine itself.

30. The Lever.— The lever may be any bar sufficiently rigid to retain its form when forces are applied to it. The terms used in speaking of the action are the *fulcrum, power-arm* and *weight-arm;* these are represented in Fig. 2.

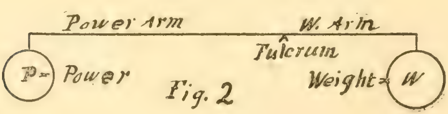


Fig. 2

There are three classes of levers, named First, Second and Third, according to the relative positions of the fulcrum to the points where the power and weight are applied; these are represented in Fig. 3.

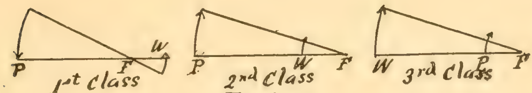


Fig. 3

The mechanical advantage of the crow-bar, in moving a heavy object, lies in the fact that it enables the muscles to generate energy at their usual relatively rapid rate, and transform it into so slow a velocity in the load to be moved that a heavy weight is required to balance the smaller, more rapidly acting power. Suppose we have a crow-bar sixty inches long, and the fulcrum is placed at two inches from one end when it is being used as a lever of the first class. In this case, as shown in Fig. 4,

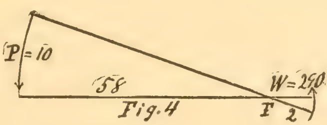


Fig. 4

both the power and the weight travel on the circumferences of circles, the power circumference having a radius of fifty-eight inches, and the weight circumference having a radius of two inches.

Now the circumferences of these two circles have the same relative lengths as their radii do, and since the lever does not bend, the weight can have a velocity only $\frac{2}{58}$ or $\frac{1}{29}$ as great as that of the power, and since the power is ten and its velocity twenty-nine times that of the weight, its *momentum* must be

$$10 \times 29 = 290;$$

and this being true, the weight, in order to just balance the power, must have mass enough so that, with a velocity of one the amount of motion shall exactly equal that of the power, and hence we have

$$1 \times 290 = 290,$$

as the load which ten will balance on a lever acting as represented.

When the crow-bar is used as represented in Fig. 5, it becomes a lever of the second class, with the power-arm sixty inches long, while the weight-arm is still two inches. In this case a power of thirty pounds will balance a load of nine hundred pounds.

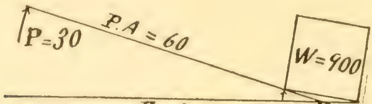


Fig. 5

When the power is applied to the lever between the weight and the fulcrum, as represented in Fig. 6, the case becomes a lever of the third class, and a power of nine hundred becomes necessary to move a load of thirty.

Fig. 6

The relation of power to weight in the case of any lever is expressed by the equation below, where P. equals power, W. equals weight, P. A. equals power-arm and W. A. equals weight-arm:

$$P. \times P. A. = W. \times W. A.$$

When any three terms in this equation are known the fourth may readily be found.

How great a load may be moved by a power of thirty pounds acting on a lever having a power-arm of twenty and a weight-arm of three?

$$
\begin{gathered}
\text{P. x P. A.}=\text{W. x W. A.}\\
30 \times 20=\text{W.} \times 3.\\
600=3 \text{ W.}\\
\text{W.}=200 \text{ lbs.}
\end{gathered}
$$

31. The Two-horse Evener.—This is a lever of the second class where the whippletree clevis-pin acts as the fulcrum for each horse, the weight or load being carried by the center pin. As ordinarily constructed this instrument is designed to divide the work of moving the load equally between the two horses. This, however, is not done at all times unless the three holes lie in the same straight line.

When the holes are bored as shown in Fig. 7 the load is divided equally only when one horse is not behind the other.

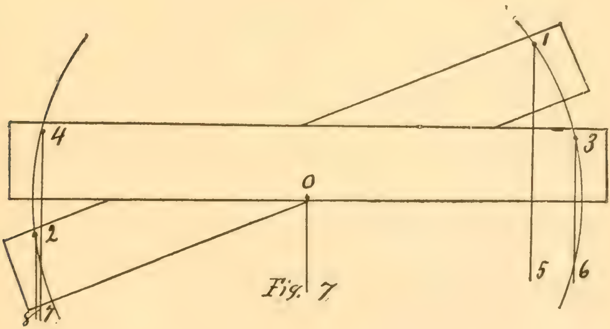


Fig. 7

The figure shows that when the near horse falls behind the other the effective length of his lever arm is diminished more than is that of the off horse, and consequently he must pull a larger share of the load.

When the holes are bored in the same straight line the possibility of this inequality is avoided, as shown in Fig. 8, because the changes in the effective lengths of the lever arms are always equal no matter which horse falls behind. This latter form, although the best so far as dividing the labor evenly between the two horses, is rarely adopted in practice, owing chiefly to the possibility of more cheaply constructing the evener the other way.

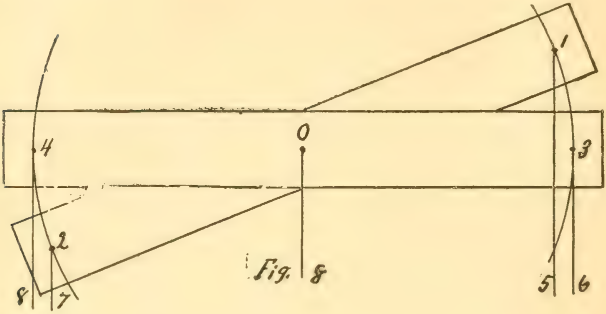


Fig. 8

Where heavy loads are to be moved, like pulling stones or stumps, or hauling a load out of a rut or out of the mud, the second type of evener will always allow a matched team to pull a larger load, because the horse which happens to be thrown behind, in attempting to start the load, is placed at a disadvantage and the other horse can only pull enough to hold his end against the one placed at a disadvantage. So, too, in doing heavy work, where one horse is naturally a little freer or stronger than the other, the tendency is always to throw more than half the work upon the slower or weaker horse.

32. "Giving One Horse the Advantage." — The frequent practice, where the two horses of a team are not equally strong, of "giving one horse the advantage" is based upon the principle that the amount of work done by each horse is inversely proportional to the length of the lever arm upon which he works. Suppose it is desired to so modify an evener that three-eighths of the work will fall upon one horse and five-eighths upon the other. In this case the horse which is to do five-eighths of the work must have his end of the evener shortened until its length is just three-fifths as long as that of the horse which is to do three-eighths of the work. If the distance from 1 to 2 in Fig. 8 is forty-eight inches, then in order to require the near horse to do five-eighths of the work the power-arm of his lever will be

$$\frac{24}{\frac{5}{8}} \text{ in.} = 38.4 \text{ inches}$$

This is given by substituting the numerical values in the general equation of the lever.

$$\text{P. x P. A.} = \text{W. x W. A.}$$
$$\text{By substituting, } \tfrac{5}{8} \text{ x P. A.} = 1 \text{ x } 24 \text{ in.}$$
$$\text{Whence, P. A.} = \frac{24}{\frac{5}{8}} \text{ in.} = 38.4 \text{ in.}$$

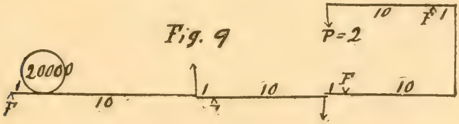
This length of 38.4 inches will be secured by setting the clevis 9.6 in. nearer the center.

How far in must the clevis be set to give the other horse an advantage of one-eighth? of one-sixteenth? of one-thirty-second?

33. Platform Scales.—Levers are often used in combination when it is desired to balance a very heavy load by a small weight, and such combinations are spoken of as compound levers. The various forms of platform scales are examples of such combinations. In the case of hay scales, four thousand to six thousand pounds are balanced or lifted by a few pounds.

The principle by which such combinations of levers gives these great mechanical advantages will be understood from Fig. 9.

Fig. 9



If F. F. F. F. are fulcrums of the levers I, II, III, IV, and their power-arms are each ten while their weight-arms are each one, then a power of two pounds at P. will balance a load of twenty thousand pounds at W. This must be so, for two pounds at P. will cause lever IV to exert a pressure of twenty pounds upon the long arm of lever III; the twenty pounds pressure of lever III will cause a pressure of two hundred pounds on lever II; lever II transmits a pressure of two thousand pounds to the end of lever I, and this pressure will sustain a load of twenty thousand pounds placed at W.

For levers in combination the continued product of the power and power-arms is equal to the weight into the continued product of the weight-arms.

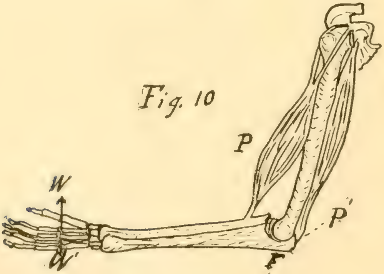
P. x P. Arms=W. x W. Arms.
or, $2 \times 10 \times 10 \times 10 \times 10 = 20{,}000 \times 1 \times 1 \times 1 \times 1$.

In the platform scales the platform is supported at its four corners by bearings which rest upon four levers, the ends of which are joined by means of a vertical rod to the short end of the graduated scale beam. The accuracy and sensitiveness of such scales depend upon the exactness with which the lever arms are constructed and the delicacy and durability of the bearings and fulcrums which transmit the pressure to the levers.

34. The Locomotion of Animals.— Most of the higher animals which travel by means of appendages to their bodies propel themselves with a system of levers which are operated by sets of very powerful muscles.

The mechanism of muscles and their method of contraction make it possible for them to move through only very small distances, and hence where considerable movements are to be executed the results are secured by attaching them to the short arms of levers. In the forearm, for example, the biceps muscle acts upon a lever whose power-arm is only one-sixth as long as the weight-arm, and hence when a weight of fifty pounds is held as represented in Fig. 10 the muscle must exert a tension of three hundred pounds.

Fig. 10



The triceps muscle which extends the forearm is a more powerful one than the biceps, and in order to accomplish its much more rapid movements it works upon a relatively much shorter lever arm, the relative lengths of the two arms being about as one to twenty or twenty-four. Now it is possible for the triceps muscle to exert a force upon a spring-balance exceeding twenty-four pounds, and hence, since

$$P. \times P.\ A. = W. \times A.,$$
$$\text{we have } P. \times 1 = 24 \times 20,$$
$$\text{and } P. = 480;$$

which proves that the triceps muscle can exert a tension of four hundred and eighty pounds. It is this powerful muscle acting upon the hammer which enables nails to be so readily driven.

The great tension which some of the muscles of horses must exert in pulling heavy loads, acting as they do at the short ends of levers, is almost beyond belief.

35. The Wheel and Axle.— With the lever only a small amount of motion can be communicated to a body at once, further movements only being possible after reversing its action. The wheel and axle, represented in Fig. 11, enables power to be applied continuously in one direction to the load or resistance to be overcome.

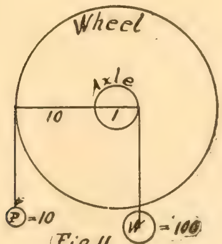


Fig. 11

The relation of power to weight in this element of machines is expressed by the equation

$$\text{Power x Power-Radius} = \text{Weight x Weight-Radius},$$

or, briefly,

$$\text{P. x P. R.} = \text{W. x W. R.},$$

and by substituting the numerical values given in Fig. 11 we get

$$10 \text{ x } 10 = 1 \text{ x } 100.$$

The relation of power to weight may also be represented in terms of the diameters or circumferences of the wheel and axle, thus:

$$\text{P. x P. R.} = \text{W. x W. R.}$$
$$\text{P. x P. Diam.} = \text{W. x W. Diam.}$$
$$\text{P. x P. Cir.} = \text{W. x W. Cir.}$$

This mechanical power has by far the most extended use of any in machinery.

36. Trains of Wheels and Axles.—Wherever a great rotary velocity is desired, as in the case of the wood saw, in the cylinder of a threshing machine, in the fan of a fanning mill, or in the much higher speed of centrifuges, several wheels and axles are joined in a train by means of belts, gears, or friction pulleys; such systems are analogous to compound levers.

The relation of power to weight both in intensity of action and in relative velocities is expressed by these equations:

1. For intensity of action:

$$\text{Power x Continued product of P. R.} = \text{Weight x Continued product of W. R.}$$
$$\text{P. x P. Radii} = \text{W. x. W. Radii.}$$

2. For velocity:

$$\text{P. x P. Velocity} = \text{W. x W. Velocity.}$$

37. The Sweep Horse-Power.—This machine is an example of a train of wheels and axles whereby the slow walk of the horses is converted into the extremely rapid rotation of the cylinder of the thresher, feed-cutter or feed-mill, the sweeps to which the horses are attached constituting radii of the first wheel in the train. Here the small amount of work required of the machines at any one instant makes a high speed of execution desirable.

38. The High Speed of Centrifuges.— This is secured by a combination of wheels and axles connected with belts. Suppose the diameter of the fly-wheel of the engine is twenty-four inches and it makes two hundred and twenty revolutions per minute. If this is belted to a six-inch axle or pulley on the driving-shaft, then the number of revolutions made by the wheel on the driving-shaft will be

$$220 \times \tfrac{24}{6} = 880.$$

If the shaft-pulley connecting with the axle of the intermediate pulley has a diameter of ten inches while the axle has a diameter of five inches, then the wheel of the intermediate pulley will make

$$880 \times \tfrac{10}{5} = 1760$$

revolutions, and if the wheel of the intermediate pulley has a diameter of twelve inches while the axle of the centrifuge is three inches, then the centrifuge will make

$$1760 \times \tfrac{12}{3} = 7040$$

revolutions per minute.

Change the diameter of a wheel or axle so as to give the centrifuge four thousand revolutions; six thousand revolutions; five thousand revolutions.

39. Exertion of Great Power.— When the exertion of a great lifting force is required at the expense of speed, this may be done by reversing the action of a train of wheels such as is considered in **38.** In that case, if the power were applied at the Centrifuge and the work done at the other end of the series, a load would be lifted very slowly indeed, but its weight could be very great.

40. The Inclined Plane.— This mechanical power is a rigid surface inclined to the line of the force or resistance which it is to overcome, and is represented in Fig. 12.

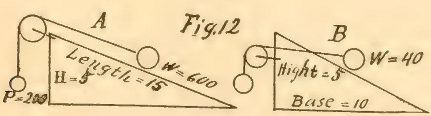


Fig. 12

When the power moves parallel with the length or face of the plane, as in A, the relation of power to weight is given by the equation

Power x Length of Plane = Weight x Height of Plane,
or $200 \times 15 = 600 \times 5$.

But when the power moves in a line parallel with the base of the plane, as in B, then the relation of power to weight is given by the equation,

Power x Length of Base = Weight x Height of Plane,
or $20 \times 10 = 40 \times 5$.

41. The Tread Power.— This method of transferring energy is a practical application of the inclined plane, and the amount which can be transmitted by it depends upon the height of the plane as compared with its length.

If the length of the tread is eight feet and it is given a slant of one foot in eight feet, then from the equation

P. x Length = W x Height

we get, with two thousand four hundred pounds as the weight of two horses,

$P. \times 8 = 2400 \times 1$,
whence P. = 300 lbs.,

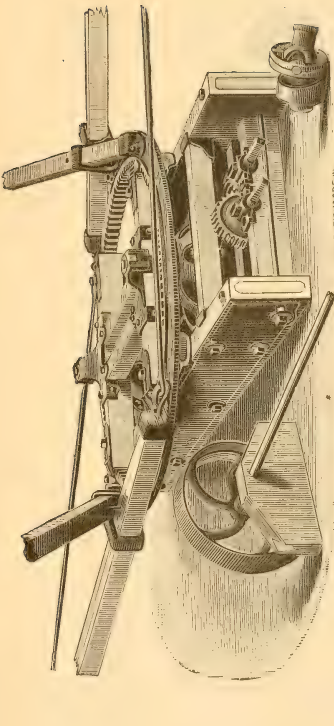
as the intensity of the power exerted, diminished, of course, by whatever friction there may be.

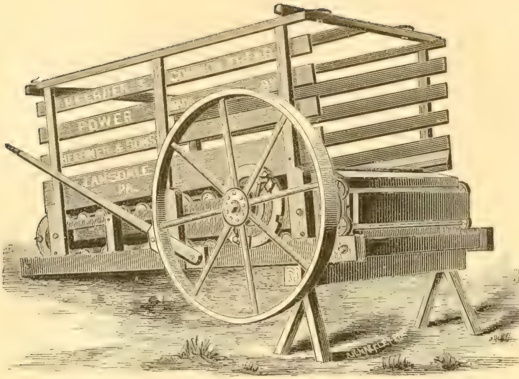
What would be the power if the slant were made one foot in seven feet? one foot in six feet? one foot in five feet?

42. Traction on Common Roads.— The power required to draw a wagon over common roads varies with the character and condition of the road. Experiments in England with a four-wheeled wagon have given the following results for level roads as indicated by a dynamometer:

On cubical block pavement	28 to 44 lbs. per ton.
On Macadam road	55 to 67 lbs. per ton.
On gravel road	125 lbs. per ton.
On plank road	27 to 44 lbs. per ton.
On common dirt roads	179 to 268 lbs. per ton.

43. Traction Power of a Horse.— According to the most reliable data available at present, which is certainly far short of what could be desired, a horse in good condition, well fed, and weighing not less than one thousand pounds, when actually walking at the rate of two and one-half miles per hour during ten hours per day, can exert a *traction of one hundred pounds* on a level road or circular horse-path like that

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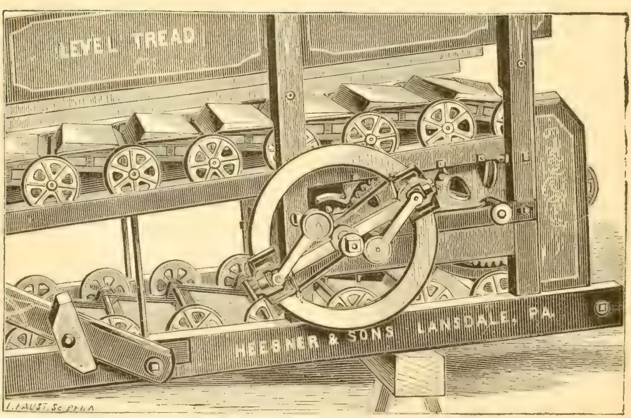
LEVEL TREAD
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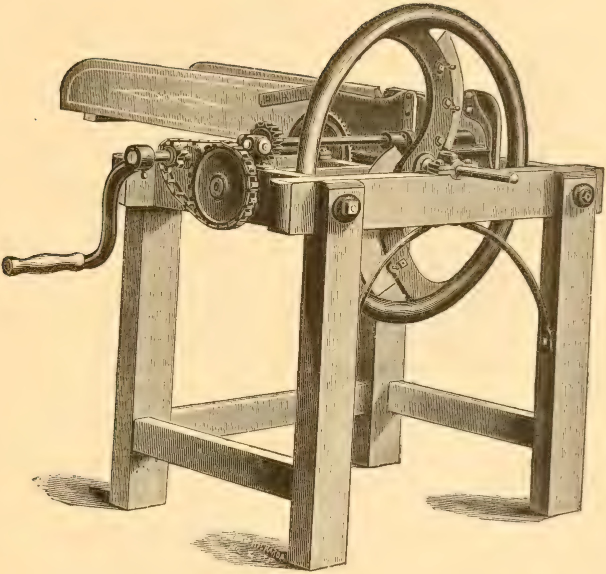

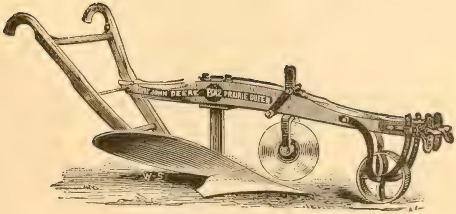
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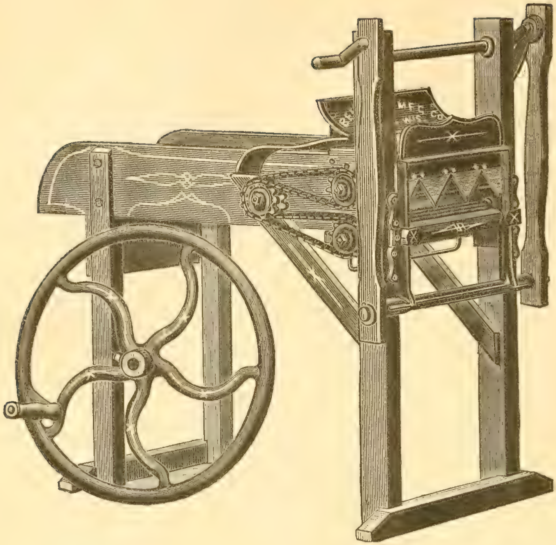

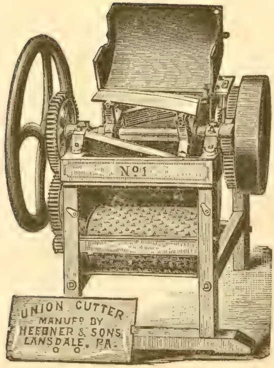
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of the sweep-powers. In order that a horse may exert his force most advantageously on a sweep-power the track should have a diameter of thirty to thirty-five feet,—never less than twenty-five.

44. Increased Speed Diminishes the Traction Power.—If the horse walks more rapidly than two and five-tenths miles per hour, or at a slower pace, the force which he can exert changes also and is less or greater than one hundred pounds. Experience seems to indicate that at speeds between three-quarters of a mile and four miles per hour, and continued ten hours per day, the traction will be given by the following equation:

$$2.5 \text{ miles} \times 100 = n \text{ miles} \times \text{Traction.}$$

Thus, at two miles per hour the traction would be:

$$2.5 \times 100 = 2 \times \text{Traction};$$
$$\text{whence, Traction} = \tfrac{250}{2} \text{ or } 125 \text{ lbs.}$$

What would be the traction at one mile per hour? at three miles? at four miles?

45. Diminishing the Number of Hours of Work per Day Increases the Traction.—When the speed remains the same, experience has shown that, between five and ten hours per day, diminishing the time increases the possible traction in about the same ratio, or

$$10 \text{ hours} \times 100 = n \text{ hours} \times \text{Traction.}$$

Thus if the horse is to be worked only five hours the traction he may exert will be

$$10 \times 100 = 5 \times \text{Traction},$$
$$\text{whence Traction} = \tfrac{1000}{5} = 200 \text{ lbs.}$$

What may the traction be when the horse works six hours? seven hours? eight hours? nine hours?

46. Traction Power Diminished by Up-Grades.—When a horse is forced to draw a load up a hill his power of traction is diminished by being forced to lift his own body at the same time. If he is going up a hill which rises one in ten he must expend a force of one hundred pounds per one thousand pounds to overcome the force of gravity on his own body, and if the load he was drawing weighed one thousand pounds the force of gravity would require another one hundred pounds to overcome the tendency of the load down the hill, leaving all resistance out of consideration. Now if an empty wagon weighs one ton, and the hauling of a ton on a level road of the same character as the hill requires one hundred and fifty pounds, then the force necessary to carry the load up the hill rising one in ten would be, for a span of horses:

For two horses	200	lbs.
For load	200	"
For rolling friction	300	"
Total	700	"
For one horse	350	"

The rate at which the horses could move up the hill with this load would be, by **44**,

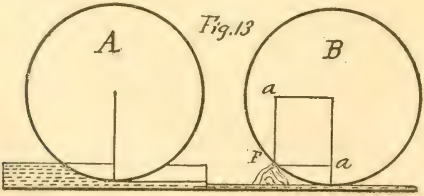
$$2.5 \times 100 = \text{rate} \times 350;$$

$$\text{whence, rate} = \tfrac{250}{350} = .7 \text{ miles per hour.}$$

What would be the force required to move the same load up a hill which rises one foot in twelve feet? one foot in thirteen feet? one foot in fourteen feet? one foot in fifteen feet?

47. Good Roads Make High Grades More Objectionable.— It is evident that the better the road-bed is made, thus reducing the traction on the level, the more objectionable a hill becomes, because the force of gravity is just as strong on a good road as on a bad one, and while a much larger load may be hauled on the level, when the hill is reached it cannot be drawn up. It was shown, in **46,** that where the traction was one hundred and fifty pounds per ton, a grade of one foot in ten feet added to that traction one hundred pounds per one thousand pounds of load, including the weight of the team. Now if the road-bed were improved so as to reduce the traction to seventy-five pounds per ton, double the load could be brought to the hill, but, unless the grade were also lessened, it could not be moved over it.

48. Soft and Uneven Roads.—The reason why the traction is so heavy on soft and uneven roads will be readily seen from a study of Fig. 13.



At A, where the wheel is continually cutting into the ground, it is, in effect, constantly tending to rise up a hill which is steadily breaking down, and whose gradient varies with the size of the wheel and the depth to which it sinks into the ground. A wheel four feet in diameter which sinks two inches into the ground is constantly tending to move up a hill which rises about one inch in five and one-third inches. If the wheel has a less diameter than four feet, not only does it sink more deeply into the ground with the same load, but, for the same depth, it is forced to tend to rise up a steeper grade.

So, too, in raising the load over an obstruction, as shown at B, there is, in a measure, the effect of rolling the load up an inclined plane which is steeper in proportion as the height of the obstruction is large and the diameter of the wheel small. This case may, however, be more exactly compared to lifting a load with a bent lever of the first class, where the obstruction is the fulcrum, the distance af the weight-arm and the distance bf the power-arm. The higher the obstruction, and the smaller the wheel, the more nearly equal are the lever arms. It is this fact which explains, in part, why heavy loads may be moved more easily over uneven roads on large wheels.

49. Wide and Narrow Wagon Tires.— The same fact which makes a large wagon wheel more advantageous on soft ground makes a wide wagon tire better than a narrow one, under the same conditions. It presents more surface to bear the load, and hence does not sink as deeply into the ground as the narrow one does, and, this being true, the load is moved with less traction. So far as lightness of draught is concerned, broad tires are best adapted to field hauling, but, for hard roads, there appears to be but little advantage in this particular. On soft roads the broad tires would be of advantage, provided all wagons using the road were of this character, for then the cutting of the roads would be less and the draught lighter. There is, however, one serious disadvantage of wide tires on an improperly drained road composed of sticky soil: during wet times the wheels so fill with mud between the spokes that the wagon becomes a load in itself.

50. The Telford System of Road Construction.— The essential features of the system followed by this great English road-engineer may be briefly stated to consist in first leveling and thoroughly draining the road-bed, then to lay upon it a solid pavement of large stones, these covered with a layer of stones carefully broken, and the whole then covered with a layer of gravel or other fine material. This was the system he followed in the Highlands of Scotland.

But where much heavier traffic was to be provided for, the middle of the road-bed was made as firm as possible by forming a pavement of large stones which were carefully laid by hand on a bed formed to the proper shape of the road and previously well drained. All inequalities were broken off the tops of these stones and the cavities filled in, the size of the stone being 7x3 inches. Over this paving was placed a layer of whinestone — a hard basaltic rock — seven inches in thickness, the pieces being broken so that none should exceed six ounces in weight and all be able to pass though a circular opening two and one-half inches in diameter. This layer was again covered with binding gravel sufficient to fill up all the cavities. Great attention was paid to this road until it became thoroughly settled and then it stood the heavy traffic between Carlisle and Glasgow for six years, nothing being required beyond cleaning the dirt off during that time.

51. The Macadam System of Road Construction.— This differed from the Telford system in that it aimed to secure, instead of the hard unyielding surface of that system, a certain amount of elasticity. Macadam, after preparing his road-bed essentially as described in the Telford system, laid upon it several inches of angular fragments broken from the hardest rock he could find, preference being given to granite, greenstone or basalt. This layer was carefully watched by men, and as ruts appeared they were raked full and fresh material added until a hard, even surface was secured.

52. Road Drainage.— Perfect drainage is one of the first requisites of a good road, and in some places both surface and under drainage may be required. If the contour of a road is such that the water of rains may stand upon it in places, at all such points the road-bed softens and ruts are cut more or less deeply into it. In the construction of a road, therefore, the aim should be to give the surface such a contour that all rain is shed completely from it, and, at the same time, to depart as little from the horizontal section as possible. In Fig. 14 is given a profile of the Telford road-bed.

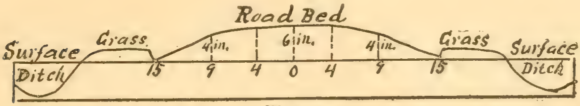


Fig. 14

The section adopted by Telford is quite flat and more nearly a portion of the side of a flat ellipse than the arc of a circle. It will be seen that in a road-bed thirty feet wide the fall, in the first four feet from the center, is only half an inch, in nine feet two inches, and in fifteen feet six inches. The aim is to have the road-bed as nearly flat as may be in the central eighteen feet so as not to tilt the load and force the traffic to follow one line. The tendency is to get the surface too sloping, and when this is done the weight of high loads is thrown more upon the lower set of wheels, which tends to develop ruts on that side; there is also a tendency to slide, so that the wear on the road-bed and upon the wagon-tire is increased. The ridge, upon the two sides, is intended to keep stones and dirt from being thrown into the side drainage ditches. The road-bed is often made only eighteen feet wide and the two level strips used, one as a foot-path and the other as storage ground for crushed rock and gravel to be used in repairing the road.

Where underdrainage is needed, two lines of tile are laid, one on each side just outside of the road-bed but inside of the sided ditches as shown in Fig. 15.

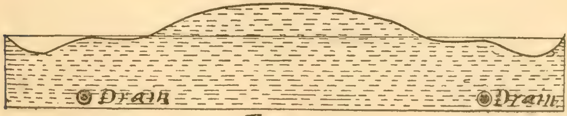


Fig. 15

The two lines of tile are used to prevent water from running under the road-bed from either side to soften up the ground, the surface, when properly made and kept in repair, keeping water from entering from above.

53. Results of General Morin's Experiments in France.— General Morin, after a series of experiments carried on at the expense of the French government, reached the following general conclusions regarding roads and carriages:

1. The traction is directly proportional to the load, and inversely proportional to the diameter of the wheel.

2. Upon a paved or hard macadamized road the traction is independent of the width of the tire when it exceeds three to four inches.

3. At a walking pace the traction is the same for carriages with springs as for those without springs.

4. Upon a macadamized or paved road the traction increases with the speed above a velocity of two and one-quarter miles per hour.

5. Upon soft roads of earth or sand the traction is independent of the velocity.

6. The destruction of the road is in all cases greater as the diameters of the wheels are less, and it is greater by the use of carriages without springs than of those with them.

54. The Pulley.— This mechanical power consists of a wheel, having a grooved circumference through which a cord or chain may pass, and so mounted as to revolve freely about an axis. Pulleys are spoken of as either *fixed* or *movable*, according as the axis of revolution is stationary or travels with the load it carries. The two types are represented in Fig. 16.

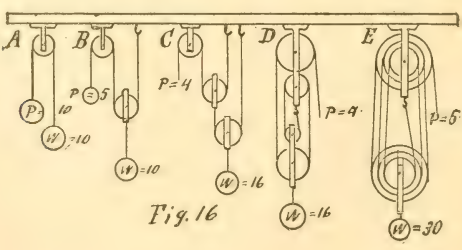


Fig. 16

At A is represented a simple fixed pulley in which the power must be equal to the weight, because, in this case, the pulley may be regarded as a lever of the first class, where the axle of the pulley becomes the fulcrum, and then the two arms are of equal length, each being a radius of the pulley. At B the lower pulley is movable, traveling upward with the load, and here we have the equivalent of a lever of the second class, with the fulcrum at the side of the pulley in contact with rope 2. As the load hangs from the axis of the pulley the power-arm is the diameter of the pulley and the weight-arm is the radius, giving us the equation:

$$P. \times P.\ A. = W. \times W.\ A.$$
$$\text{or } 5 \times 2 = 10 \times 1.$$

At C, D and E are combinations of several movable and fixed pulleys. In C we have a system with several separate cords, and in this the relation of power to weight is expressed by the equation

$$P. \times 2^n = W.,$$

where n equals the number of movable pulleys, or in C,

$$P. \times 2^2 = W.,$$
$$\text{whence, } 4 \times 2 \times 2 = 16.$$

In D and E we have two systems of pulleys where a single continuous cord is used. It makes no difference whether the pulleys are arranged side by side, as in D, or one above the other, as in E, the relation of power to weight is expressed by the equation:

$$P. \times \text{No. cords supporting } W. = W.,$$
$$\text{whence for D, } 4 \times 4 = 16,$$
$$\text{and for E, } 4 \times 6 = 24.$$

These equations always suppose no loss due to friction or in bending the ropes. There is, however, always a large and variable loss, so the actual lifting power is less than the theoretical.

55. The Horse-fork and Pulley.— The horse-fork and carrier are used in lifting hay, as represented in Fig. 17. The mechanical advantage is that of pulley B, Fig. 16, diminished, of course, by the friction.

When no pulley is used next to the fork, the traction exerted by the horse must always considerably exceed the weight of hay lifted, so that a single horse is fully tasked in freeing from the load and raising from two hundred to three hundred pounds of hay.

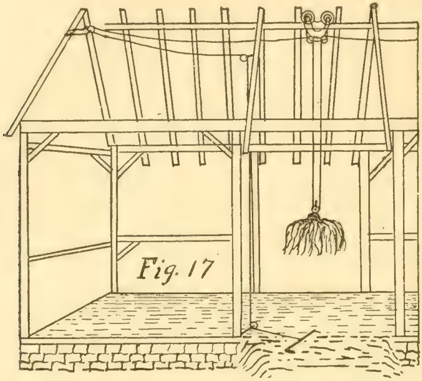


Fig. 17

56. Using the Pulley to Raise Heavy Stone Out of the Ground.—The pulley may frequently be used to advantage in raising heavy stone out of the ground, and in pulling stumps, as shown in Fig. 18.

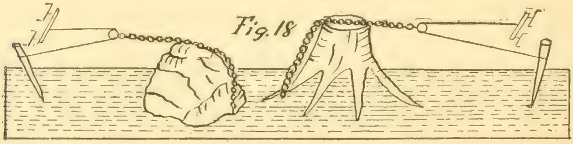


Fig. 18

If a pulley is fixed to the chain in either of the above cases, and the team draws upon a rope passing through it to a fixed attachment, as shown, two horses will exert the traction of four upon the stump or stone, diminished by the friction of the pulley. If the chain is attached to the stone, and so passed over the top as to roll, instead of drag, it from its place, the mechanical advantage will be still greater.

57. The Screw.—This mechanical power is practically a combination of the inclined plane and the lever. The threads of the screw, and of the nut also, represent inclined planes free to slide one upon the other. One or the other of these inclined planes is fixed while the other is moved by means of a lever of some form, the movable one carrying the load.

When the distance between the threads of a screw is one-fourth of an inch and the circumference described by the end of the lever to which the power is applied is three feet, the theoretical load lifted by a power of one hundred pounds is

$$100 \times 3 \times 4 \times 12 = 14{,}400.$$

But the friction is so variable, and so great with very heavy loads, that it is practically impossible to calculate, from theory, the load which may be thus moved. None of the mechanical powers can be so compactly constructed as this, and at the same time allow so small a force to exert so great a pressure. It is on this account that the screw is so much used in the construction of vices, lifting-jacks and presses.

58. Friction Between Solids.— When one surface rests upon another the roughness or inequalities of the one fit, to a greater or less extent, into those of the other, so that in order that one may be moved upon the other either the two bodies must be, to some extent, separated, or else the interlocking roughness must be broken away. We have seen that molecules are not in contact in bodies, and also that they are very small; from this it follows that no matter how smooth two surfaces may appear there are always present inequalities of surface and always a resistance which opposes sliding, and this is called *friction.*

59. The Friction of Rest or Static Friction Between Solids.— When two surfaces have been at rest with reference to each other for a time there is developed the maximum amount of interlocking, and hence the greatest amount of friction. This is analogous to a load standing upon a wagon over night, causing the wheels to become depressed in the surface upon which they rest. The load is started with greater difficulty because the wheels must be rolled out of depressions, and this illustrates the condition of static friction. On the other hand, if the wagon moves rapidly with its load, especially if over soft ground, the wheels do not have time to form deep depressions in the surface, and the resistance to forward progress is smaller, and this is, in a measure, analogous to friction of motion.

60. The Friction of Motion or Kinetic Friction Between Solids.—When two surfaces are sliding rapidly one over the other there is not time to change direction and develop the interlocking which is possible with a state of rest, and consequently less power is lost when one solid slides rapidly over another.

61. Influence of Pressure on the Friction of Solids. When other things remain the same, increasing the pressure increases the friction, and the amount of friction is directly proportional to the pressure. Thus if one hundred pounds produce a friction of two pounds, one thousand pounds will develop a friction of twenty pounds, and this is independent of the amount of surface bearing the load provided the pressure is not great enough to crush or tear the surfaces.

62. Friction Between Liquids and Solids.—In this case the amount of friction follows a different law, for it increases with the amount of surface and also with the square of the velocity of sliding motion. It is, however, less than that between solids and solids, and because of this fact the oiling of the bearings of machinery diminishes very much the loss of effective energy through friction.

Where the velocities of revolution are slow, thick oils, like castor oil, develop but little friction, but as the speed is increased the friction increases very rapidly, and this fact makes a thick viscous oil inapplicable as a lubricant where high velocities, like those of the bowls of centrifuges, are required. On the other hand, when a very thin fluid is used as a lubricant for slow motions there is time for such freely-flowing fluids to be crowded out of inequalities and thus allow the interlocking of solid surfaces to be partially set up and develop a high friction for these low speeds which the thick slow-flowing oils prevent; but for very high speeds the thin fluid is able to maintain the depressions of the solid surfaces full, and the much smaller internal friction of the thin oil gives rise to a relatively lower friction for such speeds.

It is upon this same principle, in part, that a thick grease serves so well the purpose of a lubricant to lessen friction in the slow sliding which obtains in the axles of a wagon.

63. Bad Effects of Dirt in Journals.—When grit of any kind becomes entangled in the lubricants of any journal or friction surface these particles bridge across or cut the two films of oil which closely adhere to the two sliding surfaces, so that friction is set up between solids rather than between liquids as it should be, and there results not only a great loss of energy transmitted by the machine, but also an excessive wear of the bearings, which quickly destroys the fit so essential to steady, easy and economical motion. Scrupulous cleanliness of the friction surface of farm machinery should therefore be adhered to as well as ample lubrication.

64. Belting.—The transmission of power by means of belting is a useful application of the friction between solid surfaces. In order that power may be economically transmitted by this means the belt must be so tight that little slipping takes place, and for leather belts this is least when the pulley is covered with leather, hair side out, and the belt runs upon this, hair side in. When the belt is running at a high speed the tension may be less in proportion to the power transmitted, the *activity* of belting being expressed by the equation:

$$\text{Activity} = Tv,$$

where v is the velocity and T the effective tension. When the velocity is very great the tension may evidently be small, and yet the *activity* or horse-power remain large. It is on this account that small wire cables may be used at very high velocities in transmitting very large amounts of energy.

It is in consequence of this principle, too, that light ropes are successfully used in transmitting energy to the centrifuge.

65. Sliding Friction in Machinery is Lost Energy.—The sliding of the inequalities of friction surfaces over one another sets the molecules constituting them into a state of to-and-fro motion, and all such motions represent energy lost either in the form of heat or of sound; and it is because no machine can be so constructed as to run absolutely frictionless that they, one and all, fail to transmit all the energy which is imparted to them, and hence it is that perpetual motion is an impossibility.

66. Friction in the Churn.— In all forms of churns the agitation of the cream results in friction between the molecules of milk and between the milk and the parts of the churn, and this causes a transformation of the energy brought to the churn from the source of power largely into heat in the milk, which causes its temperature either to actually rise or else prevents it from cooling as rapidly as it would otherwise do. Now, if churning is begun with the cream at too high a temperature and the surrounding atmosphere is also too high, bad results must necessarily follow.

STRENGTH OF MATERIALS.

67. A Stress.— When a post is placed upon a foundation and a load of two thousand pounds is set upon it, the post is undergoing or opposing a *stress* of two thousand pounds. When a rope is supporting a load of one thousand pounds in a condition of rest it is subject to a *stress* of one thousand pounds. The joists under a mow of hay are subjected to a *stress* measured by the tons of hay which they carry.

68. Kinds of Stress.— Solid bodies may be subjected to three classes of stresses which tend to break them and will do so if the stress is great enough. These are:

1. A crushing stress, where the load tends to crowd the molecules closer together, as when kernels of corn are crushed between the teeth of an animal.

2. A stretching stress, as where a cord is broken by a load hung upon it.

3. A twisting stress, as where a screw is broken by trying to force it into hard wood with a screw-driver.

69. Strength of Moderately Seasoned White and Yellow Pine Pillars.— Mr. Chas. Shaler Smith has deduced, from experiments conducted by himself, the following rule for the strength of moderately seasoned white and yellow pine pillars:

RULE.— *Divide the square of the length in inches by the squre of the least thickness in inches; multiply the quotient by .004 and to this product add 1; then divide 5,000 by this sum, and the result is the strength in pounds per square inch of area of the end of the post. Multiply this result by the area of the end of the post in inches, and the answer is the strength of the post in pounds.*

In applying this rule in the construction of farm buildings the timbers should not be trusted with more than one-sixth to one-fourth of the theoretical load they are computed to carry, because the theoretical results are based upon averages, and there is a wide variation in the strength of individual pieces.

TABLE OF BREAKING LOAD, IN TONS, OF RECTANGULAR PILLARS OF HALF SEASONED WHITE OR YELLOW PINE FIRMLY FIXED AND EQUALLY LOADED, COMPUTED FROM C. S. SMITH'S FORMULA:

LENGTH IN FEET.	DIMENSIONS OF RECTANGULAR PINE PILLARS IN INCHES.													
	4x4	4x6	4x8	4x10	4x12	6x6	6x8	6x10	6x12	8x8	8x10	8x12	10x10	10x12
	tons.	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*	*tons.*
8	12.1	18.1	24.2	30.2	36.3	44.5	59.3	74.1	88.9	101.7	126.9	152.3	182.7	219.2
10	8.7	13.0	17.4	21.7	26.1	34.6	46.2	57.7	69.2	84.2	105.3	126.3	158.6	190.3
12	6.5	9.7	12.9	16.1	19.4	27.2	36.3	45.4	54.4	69.7	87.1	104.5	136.7	164.0
14	5.0	7.4	9.9	12.4	14.9	21.7	29.0	36.2	43.5	57.9	72.3	86.8	117.4	140.9
16	3.9	5.9	7.8	9.8	11.7	17.7	23.5	29.4	35.3	48.4	60.6	72.7	101.0	121.2
18	....	....	....	....	....	14.6	19.4	24.3	29.1	40.8	51.0	61.2	87.2	102.6
20	....	....	....	....	....	12.2	16.2	20.3	24.3	34.8	43.4	52.1	75.7	90.8
22	....	....	....	....	....	10.3	13.7	17.2	20.6	29.9	37.4	44.8	65.8	79.0
24	....	....	....	....	....	8.8	11.7	14.7	17.6	25.9	32.3	38.8	57.9	69.4

70. Tensile or Stretching Strength of Timber.— The tensile strength of materials is measured by the least weight which will break a vertical rod one inch square firmly and squarely fixed at its upper end, the load hanging from the lower end. Below are given the results of experiments with different varieties of wood, but the strengths vary greatly with the age of the trees, with the portion of the tree from which the pine comes, the degree of seasoning, etc.

Elm	6,000	lbs. per sq. in.
Am. Hickory	11,000	" " " "
Maple	10,000	" " " "
Oak, white and red	10,000	" " " "
Poplar	7,000	" " " "
White pine	10,000	" " " "

71. Tensile or Cohesive Strength of Other Materials.

Am. cast iron	16,000 to 28,000	lbs. per sq. in.
Wrought iron wire, annealed	30,000 to 60,000	" " " "
Wrought iron wire, hard	50,000 to 100,000	" " " "
Wrought iron wire ropes, per sq. in. of rope	38,000	" " " "
Leather belts, 1,500 to 5,000, good	3,000	" " " "
Rope, manilla, best	12,000	" " " "
Rope, hemp, best	15,000	" " " "

72. Transverse Strength of Materials.—When a board is placed upon edge and fixed at one end as represented at A, Fig. 19, a load acting at W puts the upper edge under a crushing stress.

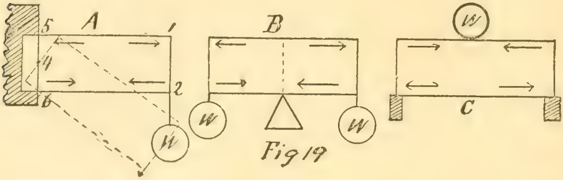


Fig 19

We know from experience that in case the board breaks under its load when so situated the fracture will occur somewhere near 5–6. Now in order that this may take place, there must be, with white pine, according to **70,** a tensile stress at the upper edge of ten thousand pounds to the square inch, and if the board is one inch thick the upper inch should resist a stress of ten thousand pounds at any point from 5 to 1; but we know that no such load will be carried at W. The reason for this, and also for its breaking at 5 rather than at any other point, is found in the fact that the load acts upon a lever arm whose length is the distance from the point of attachment of the load to the breaking point, wherever that may be, and this being true the greatest stress comes necessarily at 5.

If the board in question is forty-eight inches long and six inches wide, it will, in breaking, tend to revolve about the center of the line 5–6, and the upper three inches will be put under a longitudinal strain, but according to **70,** it is capable of withstanding

$$3 \times 10{,}000 \text{ lbs.} = 30{,}000 \text{ lbs.}$$

without breaking; but in carrying the load at the end, as shown, this cohesive power is acting at the short end of a bent lever whose mean length of power-arm is one-half of 4-5 or 1.5 inches, while the weight-arm is forty-eight inches in length. It should, therefore, only be able to hold at W. 937.5 pounds; for

$$\text{as P. x P. A.} = \text{W. x W. A.},$$
$$\text{we have } 3{,}000 \times 1.5 = \text{W.} \times 48,$$
$$\text{whence W.} = \tfrac{45000}{48} = 937.5 \text{ lbs.}$$

When a board, in every respect like the one in A, Fig. 19, is placed under the conditions represented in either B or C, Fig. 19, it should require just four times the load to break it, because the board is practically converted into two levers whose power-arms remain the same, but whose weight-arms are only one-half as long each.

73. The Transverse Strength of Timbers Proportional to the Squares of their Vertical Thicknesses.—Common experience demonstrates that a joist resting on edge is able to carry a much greater load than when laying flatwise. If we place a 2 x 4 and a 2 x 8, which differ only in thickness, on edge, their relative strengths are to each other as the squares of 4 and 8, or as 16 to 64. That is, the 2 x 8, containing only twice the amount of lumber as the 2 x 4, will, under the conditions named, sustain four times the load. The reason for this is as follows: In Fig. 20 let A represent a 2 x 4 and B a 2 x 8.

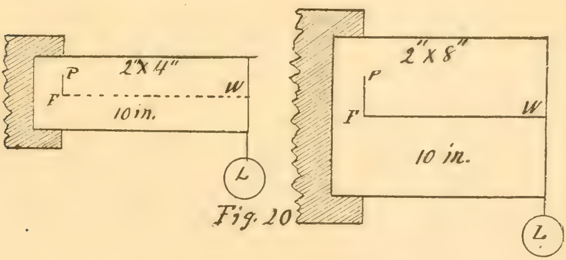


Fig. 20

In each of these cases the load draws lengthwise upon the upper half of the joist, acting through a weight-arm F. W. ten inches in length, to overcome the force of cohesion at the fixed ends, whose strength, according to **70**, is ten thousand pounds per square inch, or a total

of 2 x 2 x 10,000 lbs.=40,000 lbs. in the 2 x 4 joist,
and of 2 x 4 x 10,000 lbs.=80,000 lbs. in the 2 x 8 joist.

These two total strengths become powers acting through their respective power-arms F. P., whose mean lengths are, in the 2 x 4 joist, one inch, and in the 2 x 8 joist, two inches.

Now we have, from **30**,

P. x P. A.=W. x W. A.,

and substituting the numerical values, in the 2 x 4 joist, we get

$$4 \times 10{,}000 \times 1 = W. \times 10,$$
$$\text{or } 4 \times 10{,}000 = 10\ W.,$$
$$\text{and } W. = 4{,}000.$$

Similarly, by substituting numerical values in the case of the 2 x 8 joist, we get

$$8 \times 10{,}000 \times 2 = W. \times 10,$$
$$\text{or } 16 \times 10{,}000 = 10\ W.,$$
$$\text{and } W. = 16{,}000.$$

It thus appears that the loads the two joists will carry are to each other as four thousand is to sixteen thousand, or as one is to four; but squaring the vertical thickness of the two joists in question we get for the 2 x 4 joist

$$4 \times 4 = 16,$$
and for the 2 x 8 joist
$$8 \times 8 = 64;$$

but sixteen is to sixty-four as one is to four, which shows that the transverse strengths of similar timbers are proportional to the squares of their vertical diameters.

74. The Transverse Strength of Materials Diminishes Directly as the Length Increases.— It will be readily seen, from an inspection of Fig. 20, that lengthening the pieces of joists, while the other proportions remain the same, lengthens the long arm of the lever, while the short arm remains unchanged; and since the force of cohesion remains unaltered, the load necessary to overcome it must be less in proportion as the lever arm upon which it acts is increased. Thus, if the 2 x 8 in Fig. 20 is made twenty inches long, we shall have, from **30,**

$$P. \times P.\ A. = W. \times W.\ A.,$$

and by substituting the numerical values we get

$$80{,}000 \times 2 = W. \times 20,$$

hence

$$W. = 8{,}000,$$

instead of sixteen thousand, as found in **73.**

75. The Constants of the Transverse Breaking Strength of Wood.— Since the laws given in **72, 73** and **74** apply to all kinds of materials, it follows that the actual breaking strength of different kinds of materials will depend upon the cohesive power of the molecules as well as upon the form and dimensions of the body which they constitute. The breaking strength of a beam of any material is always in proportion to its breadth, multiplied by the square of its depth, divided by its length, or,

$$\frac{\text{Breadth x the square of the depth}}{\text{its length,}}$$

and if the breadth of a piece of white pine in inches is four, its depth in inches ten, and its length in feet ten, we shall have, taking the length in feet,

$$\frac{4 \times 10 \times 10}{10} = 40.$$

Now if we find by actual trial, by gradually adding weights to the center of such a beam, that it breaks at eighteen thousand pounds (including half its own weight), the ratio between this and forty will be

$$\frac{18{,}000}{40} = 450,$$

and as this ratio is always found for white pine, when the breadth and depth are taken in inches and the length in feet, no matter what the dimensions of the timbers may be, four hundred and fifty is called its *breaking constant for a center load.*

For other materials this constant is different, and has been determined by experiment and given in tables in various works relating to such subjects. The following are taken from Trautwine:

76. Breaking Constants of Transverse Strength of Different Materials.—

WOODS.	
American White Ash	650 lbs.
Black Ash	600 "
Yellow American Birch	850 "
American Hickory and Bitter-nut	800 "
Larch and Tamarack	400 "
Soft Maple	750 "
American White Pine	450 "
American Yellow Pine	500 "
Poplar	550 "
American White Oak	600 "
American Red Oak	800? "
METALS.	
Cast iron	1,500 to 2,700 lbs.
Wrought iron bends at	1,900 to 2,600 lbs.
Brass	850 lbs.

77. To find the Quiescent Center Breaking Load of Materials having Rectangular Cross-sections when Placed Horizontally and Supported at Both Ends.— In placing joists and beams in barns it is important to know the breaking load of the timbers used. This may be determined with the aid of the following rule and the table of constants given in **76:**

RULE.—*Multiply the square of the depth in inches by the breadth in inches and this by the breaking constant given in 76; divide the result by the clear length in feet, and the result is the load in pounds.*

But in the case of long, heavy timbers and iron beams one-half of the clear weight of the beam must be deducted because they must always carry their own weight.

$$\text{Breaking load} = \frac{\left.\begin{array}{c}\text{Square of}\\ \text{depth}\\ \text{in inches}\end{array}\right\} \times \text{Breadth in inches} \times \text{Constant}}{\text{Length in feet.}}$$

What is the center breaking load of a white pine 2 x 12 joist twelve feet long?

$$\text{Breaking load} = \frac{12 \times 12 \times 2 \times 450}{12} = 10{,}800 \text{ lbs.}$$

What is the breaking load for the same ten feet long? fourteen feet long? sixteen feet long? eighteen feet long?

Solve the same problems for other woods.

78. General Statements Regarding the Quiescent Breaking Loads of Uniform Horizontal Beams.—If the center quiescent breaking load be taken as 1, then, when all dimensions are the same, to find the breaking load:

(1) When the beam is fixed at both ends and evenly loaded throughout its whole length, multiply the result found by **77** by two.

(2) When fixed at only one end and loaded at the other, divide the result obtained by **77** by four.

(3) When fixed only at one end and the load evenly distributed, divide the result obtained by **77** by two.

(4) To find the breaking load of a cylindrical beam, first find the breaking load of a square beam having a thickness equal to the diameter of the log and multiply this result by the decimal .589.

79. Breaking Load of Rafters.— In finding the breaking load of timbers placed in any oblique position as shown in Fig. 21, take the length of the rafter equal to the horizontal span ac and proceed as in **77 and 78.**

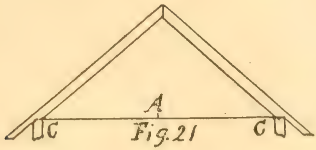


Fig. 21

80. Table of Safe Quiescent Center Loads for Horizontal Beams of White Pine Supported at Both Ends.— In this table the safe load is taken at one-sixth of the theoretical breaking load. This large reduction is made necessary on account of the cross-grain of timbers and joists and the large knots which weaken very materially the pieces. Where a judicious selection is made in placing the joists, laying the inherently weak pieces in places where little strain can come upon them, much saving of lumber may be made.

Depth in Inches.	Span 10 feet.			Span 12 feet.			Span 14 feet.			Span 16 feet.		
	Breadth.			Breadth.			Breadth.			Breadth.		
	2 in.	4 in.	6 in.	2 in.	4 in.	6 in.	2 in.	4 in.	6 in	2 in.	4 in.	6 in.
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
4	240	480	720	200	400	600	172	344	516	150	300	450
6	540	1080	1620	450	900	1350	386	772	1158	336	672	1008
8	960	1920	2880	800	1600	2400	686	1372	2058	600	1200	1800
10	1500	3000	4500	1250	2500	3750	1072	2144	3216	936	1872	2808
12	2160	4320	6180	1800	3600	5400	1544	3088	4632	1350	2700	4050
	Breadth.			Breadth.			Breadth.			Breadth.		
	8 in.	10 in.	12 in.	8 in.	10 in.	12 in.	8 in.	10 in.	12 in.	8 in.	10 in.	12 in.
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
4	960	1200	1440	800	1000	1200	688	860	1032	600	750	900
6	2160	2700	3240	1800	2250	2700	1544	1930	2316	1344	1680	2016
8	3840	4800	5760	3200	4000	4800	2744	3430	4116	2400	3000	3600
10	6060	7500	9000	5000	6250	7500	4288	5360	6432	3744	4680	5616
12	8640	10800	12960	7200	9000	10800	6176	7720	9264	5400	6750	8100

FLUIDS.

81. Surface Tension of Liquids.—The molecules of liquids exert an attractive force upon one another, but this is most manifest at their surfaces because the interior molecules, being pulled equally on all sides by surrounding molecules, have their tendency to move balanced in every direction. The surface conditions, however, are different, as will be seen from Fig. 22, where the arrows at A and B show the direction of the action of molecular forces on the interior and surface molecules respectively. The unbalanced condition of forces between the surface molecules of liquids causes them to act like a thin elastic membrane or skin upon the liquid within. It is the tension of these films which causes rain drops, and the shot from the shot towers to assume the spherical form when falling. The same action gives this form to the fat globules of milk, to dew drops on cabbage leaves and to drops of water on a dusty surface. It is this same surface tension which sustains a fine needle on the surface of water and which enables certain insects to walk upon water.

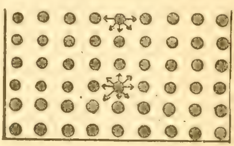


Fig. 22.

82. Strength of Surface Tension.—The strength of the tension of fluid surfaces is different for different liquids, and it varies with the surfaces which are in contact. The following table gives the relative surface tensions in certain cases:

Between clear water and air	82, nearly.
Between olive oil and air	37, nearly.
Between chloroform and air	31, nearly.
Between water and olive oil	21, nearly.
Between water and chloroform	30, nearly.

These differences of tension give rise to a great variety of phenomena. When oil is placed on water it tends to spread out indefinitely in a thin sheet. On the other hand, if a little water is placed upon chloroform it tends to draw it into a sphere or drop. The reason for these facts will be understood from Fig. 23:

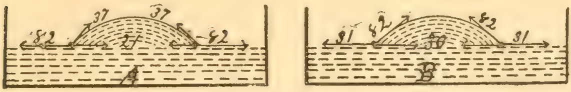


Fig. 23.

In A, on the circumference, where the drop of oil, air and water meet, the surface molecules are actuated by three sets of forces represented in direction by the arrows and in intensity by the numbers, and it is evident that the molecules so affected must move in the direction of the stronger force, and as the surface tension of the water-air surface is strongest, the oil is drawn out indefinitely until an extremely thin film results. It is on this account that so small a quantity of oil put overboard by a vessel at sea, in times of storm, covers so large an area as often to effectually protect the vessel from the dangers of wave-action. It is in accordance with the same principle that water and other fluids spread out over the surfaces of solids which they will wet.

In the case of B, where a drop of water is placed upon chloroform, the conditions of A are reversed and the water at first tends to draw up into a sphere. It is in the same manner also that water on a dusty floor or on cabbage leaves is drawn up into drops.

83. Capillary Action.—When slender glass and other tubes, whose adhesive force for water is greater than the attraction of the molecules of water for one another, are placed vertically in water, the water is seen to rise in them and come to rest above the level of the water in the surrounding vessel. It will also be observed that the hight attained by the water in different tubes varies inversely as their inside diameters. The rise of liquids in slender tubes is in accordance with the principle illustrated in Fig. 23 A, the chief difference being that the movement is in opposition to the force of gravitation and that the rise is checked when the down-pulling forces balance the surface tension.

The rise of water in soil and of oil in a lamp wick are other instances apparently due to a closely allied, if not identical action.

If, on the other hand, the attraction between the liquid and the walls of the tube is less than the attraction among the molecules themselves, so that the walls are not wet by it, the surface of the liquid in the tube is depressed, the amount being greater as the diameter of the tube is less. This depression is in accordance with the principle explained under B, Fig. 23.

84. Influence of Surface Tension on Lactometer Readings.— The rise of water on the sides of a tube floating in it, as in the case of the lactometer, tends to draw it more deeply into the liquid and thus gives a higher reading. On the other hand, if the liquid has its surface tension weakened by being overspread with oil, or if the stem of the lactometer is made greasy by handling or otherwise, it will then be lifted out of the liquid and too low a reading will be indicated. It is important, therefore, in determining the specific gravity of milk by this method to see that the lactometer is thoroughly clean.

85. Solution of Solids in Liquids.— When salt is placed in water the adhesion between the molecules of water and salt is at first stronger than the cohesion between the molecules of salt, and successive layers of salt molecules are separated and disseminated through the liquid. If the quantity of salt placed in the water be large enough, there will come a stage when the quantity of salt dissolved in the water has so weakened its adhesive power that it ceases to be strong enough to overcome the molecular cohesion of the salt and at this stage further solution is stopped.

In the majority of cases where solids are being dissolved a rise of temperature so weakens the cohesive force that solution may be carried still further. It is in part the greater solubility of soil ingredients in water at high temperatures than at low that makes a warm soil more conducive to plant growth than a cold one.

86. Diffusion.— When a phial, nearly full of salt or sugar, is placed in a vessel and the vessel carefully filled with water so as to cover the phial, the salt or sugar will in time be dispersed through the whole water. The rate at which this *diffusion* takes place is different for different substances, and in the table below, the numbers indicate the relative lengths of time required for different substances to travel the same distance in water, under like conditions.

Hydrochloric acid	1
Salt	2.33
Sugar	7
Magnesium sulphate	7
Albumen	49

All substances diffuse more rapidly at moderate temperatures than at low ones, and here is another reason why a warm soil is more conducive to plant growth than a cold one, for the transfer of food from soil to plant is partly a process of *diffusion*.

If two gases are placed in two vessels and an opening be made connecting them, the molecules of each kind of gas will travel from their respective vessels and enter the other until a uniform mixture results. We have seen that the velocities with which molecules travel are inversely proportional to their densities, and it is found that the rate of diffusion of gases obeys the same law, the lighter gas diffusing more rapidly.

Oxygen enters the air cells of our lungs and carbon dioxide leaves them by this process of diffusion, and the same thing is true of the intercellular air passages of leaves into which the stomata lead.

87. Osmosis.— In case two liquids, which mix, are placed on opposite sides of a porous membrane capable of being wet by one or both of them, currents are established in one or both directions. The membrane first becomes penetrated by the liquid having the strongest attraction for it, and on reaching the other side the liquid diffusing into it causes its attraction for the walls to be lessened, and this allows this portion to be crowded out into the liquid which has been approached and a stream thus established. If the pores in the membrane have a diameter exceeding $\frac{1}{250000}$ inch, a return current of the second liquid is established toward the first along the central portion of the pores. It is by this process that the tissues of plants and animals are nourished. Here again a warm temperature makes the streams more rapid, and so still another reason is found for having the soil in which the roots grow sufficiently warm.

Osmose of gases as well as of liquids also takes place, and it is by this process that animals get their supply of oxygen and plants their supply of carbon dioxide.

88. Viscosity.— When the molecules constituting any body are forced to move past one another their mutual molecular attraction causes a dragging which sets the disturbed molecules vibrating, and this molecular vibration is at the expense of the energy which produced the movement. This dragging effect of the molecules is called *viscosity*, and the amount of energy transformed into heat in consequence of it is a measure of the viscosity. The fat globules in rising through milk serum encounter this viscosity, and a part of the energy of the creaming force is transformed into heat, causing the cream to rise more slowly than it would if there were no viscosity.

Liquids, in flowing through pipes or other channels, are retarded by viscosity so much that in long and slender pipes the amount of water discharged is very much diminished. This fact makes it necessary, in tile draining and in conveying water in pipes to pastures or other points, to use larger pipes than would otherwise be necessary. In all those cases where the liquid wets the surface past which it flows the friction is due wholly to the viscosity of the fluid, for the layer in immediate contact with the surface remains stationary while the other molecules move past them. This is the case with oils used to diminish friction in machinery.

When the inner surfaces of pipes are rough and uneven the flow of liquids through them is further diminished by the direction of the current being changed at these inequalities and thrown toward the center of the pipes across the course of the central current. It is important, therefore, in selecting tile to avoid those having rough interiors, and also in laying them to avoid making shoulders at the junctions of the many sections.

The viscosity of air and other gases is due to the promiscuous traveling of the molecules, which causes those moving transverse to the stream to be caught in it and thus retard the onward movement, acting much as the eddy-currents set up by inequalities in the surface of water pipes.

89. Pressure of Fluids.— The great freedom of motion of molecules in masses of liquids and gases causes them to exert an internal and to transmit an external pressure equal and undiminished in all directions. The proof of this law, for liquids, is found in the fact that when two vessels are so connected that water can flow from one to the other the water will have the same hight in both vessels, no matter what form or direction the communicating passage may take. The spherical form of a soap-bubble in mid-air proves the law true for air; for if the pressure from all sides were not equal the form of the bubble would change from that of a sphere.

90. Pressure of Liquids in Vessels.— The pressure exerted by liquids on the walls of vessels which contain them is due to their weight, and, for a given liquid, is always proportional to the depth. In the following table the weight of water per cubic foot and pressure per square foot are given for different temperatures:

Tem. Fahr.	Lbs. per cu. ft.	PRESSURE IN LBS. PER SQ. FT. AT DIFFERENT DEPTHS.					
		At 2 ft.	At 4 ft.	At 8 ft.	At 10 ft.	At 20 ft.	At 40 ft.
32°	62.417	124.83	249.67	499.34	624.70	1248.34	2476.68
39°.2	62.425	124.85	249.70	499.40	624.25	1248.50	2497.00
40°	62.423	124.85	249.69	499.38	624.23	1248.46	2496.92
50°	62.409	124.82	248.64	499.27	624.09	1248.18	2496.36
60°	62.367	124.73	249.47	498.94	623.67	1247.34	2494.68
70°	62.302	124.60	249.21	498.42	623.02	1246.04	2492.08
80°	62.218	124.44	248.87	497.74	622.18	1244.36	2488.72
90°	62.119	124.24	248.48	496.95	621.19	1242.38	2484.76
212°	59.7	119.40	238.80	477.60	557.00	1194.00	2388.00

The pressure of the water on the bottom of a vessel can always be found by multiplying the area of the bottom in square feet by the depth of the water, and this product by the weight of a cubic foot of water, which is nearly 62.42.

P. on bottom=area x depth x 62.42.

The lateral or side pressure is proportional to the depth, following exactly the same law as that for the pressure on the bottom. Since the depth at the surface is zero, the lateral pressure is also zero, and since the depth at the bottom of a vessel is the greatest, the lateral pressure must there be at its maximum; these being true, the mean pressure on the side of a vessel would be the pressure at one-half the depth of the liquid, and hence, to find the total pressure on the side of a vessel, we have

$$\text{Total lateral P.} = \frac{\text{Area of sides x depth x 62.42.}}{2}$$

What is the total pressure on the bottom and on the sides of a reservoir 6 x 6 x 6 feet filled with water at 39.2° F.? at 80° F.?

What is the lateral pressure on the lower six inches of a cylindrical tank ten feet in diameter filled with water to a depth of ten feet?

If this pressure is to be sustained by an iron hoop composed of one-eighth inch band iron, how wide should the hoop be?

91. Pressure of Grain in Bins.— The downward pressure of grain in bins follows the same law as that of liquids, but the lateral pressure is always less on account of the friction between the kernels. When grain is heaped up on a level surface it is found impossible to pile beyond a certain hight without increasing the diameter of the pile at the base. A certain angle of slope is maintained, which for wheat is about 31°, about 30° for shelled corn, and for oats about 34°.

The friction of the kernels upon one another is just great enough to maintain this angle, but in filling a bin with wheat, for example, introducing it at the center, after a certain quantity has been added the base of the cone is extended until it reaches the sides of the bin, and the addition of any further quantity brings into existence an outward pressure on the walls of the bin tending to spread them. The case is analogous to the *retaining walls* which are often built to prevent sand or earth from caving or sliding. The amount of this pressure and the method of computing it will be understood from Fig. 24.

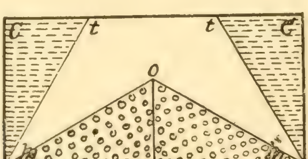


Fig. 24.

CMMC represents a section of a bin sixteen feet square and eight feet deep filled with shelled corn. The cone MOM represents the cone of grain which exerts no pressure on the sides of the bin. The remaining portion MOMCC has its weight divided between the sides and the bottom, the sides preventing it from sliding down the inclines OM, OM. The pressure on the side CM, according to the theory of retaining walls, is equal to the weight of tCM, acting as a wedge between the surfaces tM and CM. As the wedge is a movable inclined plane where the force acts parallel to the base, the pressure may be computed from the equation

Power x base=weight x hight.

The height, tC, is 4.5 feet, and the base CM, eight feet. The weight is the weight of corn composing the wedge, and is equal to

$$\frac{4.5 \times 8 \times 16 \times 1728 \times 56}{2 \times 2150.4} = 12958.72 \text{ lbs.}$$

Substituting the numerical values in the equation of the wedge above we get

Power x 8=12958.72 x 4.5, whence, power=7289.28 lbs.

as the total pressure on the side of the bin, which is an average of 56.9 pounds per square foot.

92. Pressure of Silage in Silos.—When silage is cut into a silo the pressure against the sides conforms at first to the same general law as that governing the pressure of grain in bins, as given in **91**; but it is always less than would be indicated by calculation, because the weight of the silage, combined with the fermenting processes, tends rapidly to compress the cut pieces into flat disks, which pile up as one brick does upon another, and the mass very soon becomes self-supporting, as has been proven by the silage remaining standing when the walls of large silos have been burned down within a few days after the completion of filling. When in filling a silo the silage is not evenly distributed, so that it settles unevenly, the firmer portions may act as an inclined plane down which the silage resting upon it tends to slide, and in this way give rise to a side pressure which otherwise would not exist, and in my judgment most of the disastrous pressures on the walls of silos have resulted from this unnecessary cause.

Such experiments as have been conducted to determine the pressure of silage have given results ranging from fifty-three pounds per square foot, at twelve feet deep, at the close of the second day's filling, to fifty-five pounds per square foot at twenty-one feet below the surface four days after the filling commenced.

93. The Principle of Flotation.— When a body is immersed in a fluid it is pressed or lifted upward with a force exactly equal to the weight of the fluid it displaces, and it is because of this fact that stones can be moved so much more readily under water than out of it. Thus, a stone containing exactly one cubic foot will be lifted up, when in water, with a force of 62.42 pounds, and hence appears that much lighter when moved under those conditions. It is this principle which makes possible water navigation and the ascension above the earth's surface in balloons.

94. Specific Gravity.— When the specific gravity of cast iron is spoken of as 7.2 the meaning is that a cubic inch or a cubic foot of that body weighs just 7.2 times as much as the same volume of water, and when the specific gravity of white pine is given as .4 the meaning is that a given volume of that wood weighs only .4 as much as an equal volume of water; hence, for liquids and solids, we have the equation

$$\text{Specific gravity} = \frac{\text{weight of body}}{\text{weight of equal volume of water.}}$$

Air is taken as the standard of specific gravity for gases.

95. To Find the Specific Gravity of Solids.— The principle of flotation affords a very simple means of finding the specific gravity of solids. Since any body immersed in water displaces its volume of water, and since it is also buoyed up by a weight equal to that of the water displaced, it is only necessary to weigh the body whose specific gravity is desired, both in air and in water, the difference in weight giving always the weight of a volume of water the size of the body whose specific gravity is sought. The weight of the body in air divided by this difference gives the specific gravity, and hence the rule

$$\text{Specific gravity} = \frac{\text{weight of solid in air}}{\text{loss of weight in water}}$$

Suppose a body weighs ten in air and when immersed in water only eight. In this case the weight of a volume of water equal in size to that of the body is

$$10-8=2$$

and hence, by the rule above, we have

$$\text{Specific gravity}=\frac{10}{2}=5$$

Find the specific gravity of a body weighing fifteen in air and fourteen in water. What will be its specific gravity if it weighs in water, three? one? four? six? seven? ten? twelve?

96. Table of Specific Gravities and Weights per Cubic Foot of Different Substances.—

	Sp. gr.	*Weight.*	
Ash, Am. white, dry	.61	38	lbs.
Anthracite coal, moderately shaken		58	"
Brick, common hard		125	"
Carbon dioxide, referred to air	1.5		"
Charcoal, pines and oaks		22	"
Clay, dry, in lump, loose		63	"
Coal, bituminous	1.35	84	"
Coal, bituminous, broken, loose		50	"
Copper, rolled	8.9	555	"
Earth, clay loam, dry, nat. condition		70	"
Earth, clay loam, saturated		93	"
Earth, reddish clay, dry, nat. condition		88	"
Earth, reddish clay, saturated		108	"
Earth, fine sand, nat. condition		106	"
Earth, fine sand, saturated		124	"
Elm, dry	.56	35	"
Gypsum, ground, loose		56	"
Gravel		106	"
Hemlock, dry	.4	25	"
Hickory, dry	.85	53	"
Iron, cast	7.21	450	"
Ice	.92	57.4	"
Lard	.95	59.3	"
Lead	11.38	709.6	"
Limestone, broken	1.5	96	"
Maple, dry	.79	49	"
Oak, white, dry	.77	48	"
Oak, red, black, dry		39	"
Pine, white, dry	.40	25	"
Pine, yellow, northern	.55	34.3	"
Salt, coarse		45	"
Sandstone	2.41	151	"
Snow, fresh fallen		8.5	"
Snow, compacted by rain		15.50	"
Steel	7.85	490	"
Water, 62° F.	1	62.35	"

97. To Find the Specific Gravity of Liquids.— The principle of flotation stated in **93** also furnishes an easy method of finding the specific gravity of liquids, which is done as follows: Find the difference in weight of any convenient solid in air and in water and then in the liquid whose specific gravity is desired. Suppose the solid selected loses a weight of one in water and a weight of .75 in another liquid, then a volume of water, the size of the body taken, weighs one, and an equal volume of the second liquid weighs .75. Then by the rule we have:

$$\text{Sp. gr.} = \frac{.75}{1} = .75.$$

98. The Lactometer.— The use of the lactometer in determining the specific gravity of milk is also an application of the principle of flotation, and is simply a modification of the method in **97.** In this instrument, as shown in Fig. 25, the slender and uniform stem is graduated so as to give the specific gravity by direct reading.

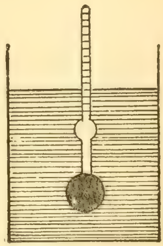


Fig. 25.

99. Atmospheric Pressure.— The air which everywhere envelops the earth to a depth probably exceeding five hundred miles has weight and exerts a pressure in all directions upon all bodies in it. This pressure, at the level of the sea, is capable of sustaining a column of mercury 29.922 inches high on the average when the temperature is at 32° F. and is equal to a pressure of 14.73 pounds to the square inch. The amount of this pressure depends always upon the total quantity of air that exists at the time above the point where the pressure is exerted. This being true, places situated above the level of the sea have a less pressure because they are nearer the upper limits of the air.

100. Variations in Atmospheric Pressure.— The pressure exerted by the air at any place is almost constantly changing, so that it is rarely the same at any two consecutive moments; these changes are not as a rule very large or very rapid. A change of one-half a pound to the square inch in twenty-four hours is a large change, and a change of one pound to the square inch never occurs during short intervals, except when very violent storms are in progress. These changes in pressure are due to the fact that the air is disturbed by currents and waves which owe their origin to various causes.

101. Soil Breathing.— When the atmospheric pressure is heavy over a given locality air is driven into the air passages in the soil of that place, and then when the pressure changes again, becoming lighter, the compressed air expands and escapes; thus there is maintained an irregular but constant breathing of the soil in consequence of these changes in atmospheric pressure. The soil breathing is further maintained, especially during the growing season, by the daily changes in temperature which occur in the upper two to five inches of soil. During the day the expansion, due to heating, forces air out and then at night the cooling causes the air left in the soil to contract and the reverse action takes place. Just how important this soil breathing is in the operations of tillage we do not know. Its amount will be increased or diminished as we increase or diminish the porosity of the soil and as we modify the conditions which affect the diurnal changes of temperature.

102. Effect of Atmospheric Pressure on Soil Water. When soil is nearly saturated with water, air can neither enter nor escape from it readily except where large openings or passages exist. In consequence of these facts, when the air pressure over a region becomes less the springs of such regions often discharge more water and the water may stand higher in the wells. The air confined in the soil and unable to escape rapidly, expands when the pressure falls and forces the water toward any openings which may exist. The reverse action also takes place when the air pressure increases, causing the water in the wells to be depressed and the same springs to discharge more slowly. "Blowing wells" owe their character also to the changes in atmospheric pressure.

103. The Suction Pump.— The common pump is one of the applications of atmospheric pressure. It should be understood, however, that the pressure of the air is in no way a source of power; it originates no part of the energy expended in pumping. Practically the only part the air plays in pumping is that of crowding the water up into the cylinder of the pump after the lifting of the piston has removed the pressure from the water in the suction pipe. The hight to which the atmosphere will sustain a column of water at sea level is thirty-four feet; but a pump producing a perfect vacuum could not raise water to that hight on account of the downward pressure exerted by the vapor of water and the air contained in water rising into the vacuum formed by the pump and exerting a pressure downward upon the column of water raised. Common pumps are necessarily so imperfect in their action that it is found impracticable to have the suction pipe longer than sixteen to twenty feet above the water to be raised.

104. Size of the Piston.— The amount of water discharged by a suction pump is determined by the length of the stroke and the area of the piston; and these in turn are determined by the strength of the pumping force and the depth of the well. In working a common pump a man can exert a pressure of only fifteen to twenty pounds comfortably upon the pump handle, and as the power-arm of the lever is only from five to seven times the length of the weight-arm the weight of water which can be lifted at one stroke cannot much exceed seventy-five to one hundred pounds. This being true, it is evident that pumps to be placed in deep wells must have smaller pistons than those placed in shallow ones. It was shown in **89** that the pressure of water is proportional to its depth, and in **90** that water forty feet deep exerts a pressure of two thousand four hundred and ninety-six pounds per square foot when at a temperature of 50° F., or at the rate of seventeen and one-third pounds per square inch, and hence the area of the piston for the pump to lift water forty feet should not exceed

$$\frac{100}{17.3} = 5.78 \text{ square inches,}$$

and this is given when the diameter of the piston is 2.7 inches. On account of the friction of the piston and of the water in the pipe and of the inertia of the water, a piston of that size would work hard in a well of that depth. In a well where the water is to be raised only twenty feet the area of the piston could be twice, and for ten feet four times, as great respectively; these would be given by diameters of 3.8 inches and 5.4 inches; but, as in the first case, they are too large for easy action. Three inches would be large for twenty feet.

105. Rate of Pumping.— The rate of discharge by a pump will be governed by the area of the piston, the length of the stroke and the number of strokes per minute. If the area of the piston is five square inches, the length of stroke five inches and the number of strokes per minute forty, then

$$5 \times 5 \times 40 = 1{,}000 \text{ cubic inches}$$

or 4.3 gallons per minute.

106. Function of Air Chambers.— In all single-acting pumps the power is able to do useful work on the piston only

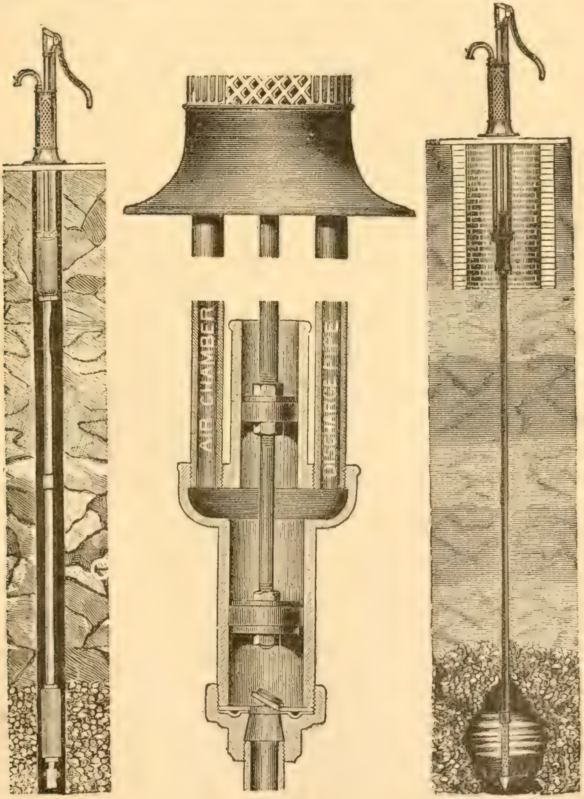


Fig. 26.

when it is moving in one direction. In deep wells, where a long column of water must be quickly set in motion and then allowed to come to rest again, the intermittent action of common pumps is a serious objection, and to avoid this, air chambers are sometimes attached. The principle of their action will be understood from a study of Fig. 26.

The air in the upper portion of the chamber, which cannot escape, is compressed by the rapid action of the piston and then, during the reverse movement, it gradually regains its original volume, forcing the water out in a nearly continuous stream. The water, therefore, is obliged to flow with only one-half the velocity of that which would be required with no air chamber, and consequently a pump having an air chamber properly placed can be worked by a wind-mill in a lighter wind than one without the air chamber. The air chamber attached commonly to pump stalks has no influence on the pumping except when the pump is used to force water above the level of the air chamber. To render the greatest service, an air chamber should be placed at as low a point as practicable in the well where there will be but a short column of water between the piston and the air chamber.

107. The Siphon.—The flow of water through the siphon is maintained by a force represented by the difference in pressure in the two arms, the siphon being kept full by atmospheric pressure. The action of the siphon is explained as follows:

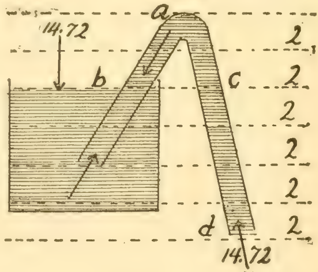


Fig. 27.

When the siphon is filled with water the downward pressure in the short arm is due to the upward pressure of the air at *d*, Fig. 27, and the downward pressure of the column of water *a b*, which, using the values in the figure, gives a total of

$$2+2+14.72=18.72.$$

The downward pressure in the long arm of the siphon is equal to the downward pressure of the column of water *a d* and the downward pressure of the air on the water in the vessel, or

$$(6 \times 2)+14.72=26.72.$$

As the two air pressures are equal and in opposite directions they balance each other, leaving the force which determines the flow the difference in the pressure of the two columns of water, or

$$12-4=8.$$

It is evident that the greater the difference in the length of the siphon arms the greater will be the velocity of discharge.

108. The Flow of Water.— When liquids move in a stream the molecules do not become separated from one another to any appreciable extent. The stream moves as a whole, the density of the liquid remaining the same in all its parts.

The flow of fluids is caused by a difference of pressure within the mass caused either by increasing it at some point or by diminishing it at another. Small velocities are associated with small differences of pressure and large velocities with large differences.

109. "Head of Water."— The velocity with which water issues from an orifice in a vessel is due to the pressure of the liquid above the center of figure of the orifice and this distance is called the *head*. If it were not for the viscosity of the water, and the resistance offered by the orifice itself, the velocity would be equal to that which a body falling in a vacuum would acquire in falling through the distance equal to the head. This is expressed by the equation

$$\text{Velocity}=\sqrt{2gH}$$

where H is the head and g is the velocity the force of gravity is able to produce in a falling body during a second of time and is equal to 32.2 feet. If the head is ten feet, then the velocity of discharge, leaving resistance out of consideration, would be

$$\text{Velocity}=\sqrt{2 \times 32.2 \times 10}=25.3.$$

What would be the velocity of discharge with a head of two feet? four feet? six feet? eight feet? twelve feet?

110. Flow of Water in Pipes.— The quantity of water discharged by pipes is very much modified by their diameters, lengths, degree of roughness, and by the presence or absence of curves or angles. Other things being the same, the greater the head the greater the discharge; the greater the length and the less the diameter the less the discharge; the greater the number of bends or angles the less the discharge.

There is no simple rule for computing the amount of water a pipe of a given length and diameter will discharge under a given head. To compute the discharge exactly the velocity of discharge at the mouth of the pipe and the area of its opening are required. Where the pipes range from .75 inch to six inches in diameter and their lengths lie between two hundred and two thousand feet, the equations below give the velocity in feet per second, but with only a rough degree of approximation.

$$\text{(1) Velocity in feet per second} = 40\sqrt{\frac{\text{diam. of pipe in feet x head in feet}}{\text{length in feet} + 54 \text{ x diam. in feet.}}}$$

This may also be expressed as below, the dimensions all being in feet:

$$\text{(2) Square of velocity in feet per second} = \frac{1600 \text{ x diam. pipe x head}}{\text{length} + 54 \text{ times diam.}}$$

In case the length of the pipe is twelve hundred to two thousand times the diameter, the factor fifty-four times diameter may be omitted without affecting the result very much. In such cases if the diameter and head are expressed in inches the velocities may be more readily determined by the following:

$$\text{(3) } v^2 = \frac{1600 \text{ x diam. x head}}{12 \text{ x } 12 \text{ x length.}}$$

If the diameter of a pipe is two inches, its length two hundred feet and the head four feet, what is the velocity of discharge?

$$\text{By (1), } v = 40\sqrt{\frac{\frac{2}{12} \text{ x } 4}{200 + 54 \text{ x } \frac{2}{12}}} = 40\sqrt{\frac{\frac{8}{12}}{\frac{2508}{12}}} = 2.259.$$

$$\text{By (2), } v^2 = \frac{1600 \text{ x } \frac{2}{12} \text{ x } 4}{200 + 54 \text{ x } \frac{2}{12}} = 5.103;$$

whence, $v = 2.259$ ft. per second.

$$\text{By (3), } v^2 = \frac{1600 \text{ x } 2 \text{ x } 48}{12 \text{ x } 12 \text{ x } 200} = 5.333;$$

whence, $v = 2.309$ ft. per second.

The last formula gives a velocity of .05 feet per second too large.

What is the velocity of discharge when the diameter of the pipe is six inches, length two thousand feet, head four feet?

To find the discharge of water in cubic feet per second, multiply the velocity in feet by the area of a cross-section of the pipe in feet.

Discharge = velocity x area of opening.

HEAT.

111. Nature of Heat.— Heat is a form of molecular energy. When a hot body is brought into contact with a cold one, the molecules comprising the hot body have their velocities slowed down by collision with the slower-moving molecules of the cold body and energy is transferred from the hot body to the cold one; and, if the contact continues, the transfer will go on until the molecular energy, per unit of weight, is equal in the two bodies. If a hot ball of iron is allowed to cool in the air, the cooling is the result of the ball *doing work* on the air. The molecules of air which come in contact with the surface of the ball are struck by the molecules of the ball and made to move away with a higher velocity than they had before, just as a ball approaching a bat is struck by it and flies to field leaving the bat motionless, a nearly complete transfer having taken place. When a cold iron is thrust into the forge fire a part of the energy of the molecules of the burning coal and of the products of combustions is transferred, by collisions, to the molecules of iron, and the temperature of the iron rapidly runs up.

112. Solar Energy.— When the sun rises the temperature of bodies upon which it shines becomes higher as a rule, and when it sets the temperature again falls, and, as a rule, continues to do so until the sun begins to shine on them again. So too, as our days grow longer and longer with the approach of summer, the mean daily temperature becomes higher, and then falls away again as the nights become longer than the days. Such, and many other facts, prove that the sun is a source of energy, and that in some manner this energy is being transferred to the earth. Since the earth travels entirely around the sun once each year, and yet each day receives energy from it, it follows also that solar energy is leaving the sun continually in all the directions in the plane of the earth's orbit, and is in fact traveling away in every other direction.

113. How Solar Energy Reaches the Earth.— When one stands on the shore of a small lake and agitates its waters in any manner, waves start out from the place of disturbance, traveling in all directions toward the bottom and the distant shore lines. When these waves reach the bottom, the shore and the air resting upon the lake, they lose a part of their energy, the lost portion being *transferred* to whatever foreign medium is struck by them. The energy generated in the muscles of the person agitating the water is thus conveyed away from him in all directions, and, sooner or later, is changed into the energy of molecular motion known as heat. The person is therefore a source of energy, which is borne away from him in the form of waves in the water and air, and this *wave-energy* becomes changed to heat, and thus the person in a small degree warms the pebbles lying on the distant margin of the lake, not by the heat of his body, but by the waves he set up in the water. It was not heat which traveled to the distant shore, but water waves which, striking the sands and pebbles, gave a part of their energy to be transformed into energy of heat in them.

The sun is wholly immersed in a cold medium called *ether* and the molecules of the sun's surface beating against this have their energy transformed into waves in it which travel away in all directions just as waves of water spread away from a disturbing body in it, but at a very much more rapid rate, the velocity being one hundred and eighty-six thousand six hundred and eighty miles per second, a speed which brings them to us in about eight minutes after their origin at the sun's surface. Sir Wm. Thompson estimates that the sun is constantly doing work upon the ether at its surface at the rate of one hundred and thirty-three thousand horse power for each square meter of its surface, and the "mechanical value of a cubic mile of sunshine" near the earth is placed at twelve thousand and fifty foot-pounds, and, as this energy is approaching us at the rate of one hundred and eighty-six thousand six hundred and eighty miles per second, the amount which falls upon a square mile of the earth's surface in that time is

$$186680 \times 12050 \text{ ft.-lbs.} = 2249494000 \text{ ft.-lbs},$$

and this is equivalent to about eighty foot-pounds per square foot each second.

114. Kinds of Ether Waves.—The molecular oscillations or vibrations at the sun's surface are not all of them at the same rate and hence they set up waves of different frequencies of vibration in the ether, the slowest known being at the rate of one hundred and seven billions of thrusts upon the ether each second and the most rapid at about the rate of forty thousand billions per second. When the wave frequencies lie between three hundred and ninety-two billions and seven hundred and fifty-seven billions per second, such waves, falling in the eye, produce the sensation of light and we speak of them as *light waves.* Waves slower than three hundred and ninety-two billions per second produce no sensation of light in the eye, but when absorbed by the skin they cause the sensation of warmth and are called *dark heat waves.* Waves more rapid than seven hundred and fifty-seven billions per second, when they fall upon the molecules of a photographer's plate, or upon a living green leaf, set up such intense vibrations in these molecules as to break them down, producing chemical changes and hence these are called *chemical waves.* It should, however, be kept distinctly in mind that there is no *light*, no *heat* and no *chemical action* until the ether waves have dashed against some molecular shore and have been wrecked upon it. When any of these waves fall upon what we call a *black* substance, like a thick layer of lamp-black, they are nearly all absorbed and the body becomes heated. On the other hand, when they fall upon a pure *white* substance, like snow, the waves rebound with nearly their full vigor and there is very little of either heating or chemical effect. When the waves fall upon what we call *green* substances, like the chlorophyl of growing leaves, most of the chemical waves and a portion of the light waves are wrecked by it and the chemical changes natural to growing leaves are the result.

115. Work Done on the Earth by the Ether Waves. It was stated in **113** that eighty foot-pounds of energy per square foot reach the earth's surface each second. This seems like an enormous amount of work when it is figured in horse power for a section of land, the amount being

$$\frac{2249494000}{550}=4089989 \text{ horse power,}$$

and it is difficult at first to realize that it can be true. To comprehend the situation we need to know that the earth is traveling through a cold region having a temperature of absolute zero or —273° C., with only the thin atmosphere to protect it from that cold. If the mean annual temperature of Wisconsin is 45° F. or 7° C., its temperature is maintained by the sun at

$$273°+7°=280° \text{ C.}$$

higher than that of the space which surrounds it. The earth is therefore rapidly sending ether waves back again into space, and thus a large part of the energy which comes to us is lost. The motions of the air, and of the water in the ocean and to and from the land, represent other portions of this energy transformed. Most of the chemical changes occurring in growing vegetation represent other transformations of solar energy, as do the activities of all forms of animal life; and when to these are added the chemical and physical changes in soils and rocks, due to it, it is plain that the amount needed to maintain the earth in its present state of activity is really very large.

116. Transfer of Heat.— When one portion of a body is heated, as in the case of a poker thrust into the fire, the heat-energy gradually spreads to the distant end. This sort of transfer is known as *conduction*, and the rate at which it occurs is very different with different materials. Metals and stone are among the best conductors, while wood, glass, water and woolen fabrics are among the poor conductors. The transfer of heat through air, where currents are prevented, takes place very slowly and it is on this account that several thin garments are warmer than the same weight of the same material as a single garment. It is on this account also that sawdust, in the walls of buildings and about ice, is so serviceable. Hollow walls with dead air spaces utilize the same principle, as does the practice of using one or more thicknesses of building paper in the construction of buildings which are designed to keep heat in or out.

When heat is applied to the lower portion of liquids or gases the conduction of heat to portions of the mass causes it to expand and become relatively lighter than that not affected, and it is, in consequence, forced to rise, thus establishing upward and downward currents. In such cases the heating is by conduction, but the heated mass is then transported, that not heated taking its place. The process is named *convection*. The third method of transfer of heat is by *radiation*, and has already been described in **113**.

117. Draught in Chimneys.— The draught in chimneys is due to two principles, one that of convection, and the other that of *aspiration*. In all properly constructed chimneys there is a draught, usually, even when there is no difference of temperature of air inside and out, and such draughts are strongest when the wind blows hardest. Why this is so will be readily understood from Fig. 28. The air, in its rapid motion across the top of the chimney, encounters the air molecules in its very top and forces them out and onward with it; this diminishes the weight of air in the chimney, and the pressure from below forces a new quantity into the moving stream which in turn is driven away. The rapid forward motion of the outer air prevents it from descending into the space left by the air forced forward. When the fire is kindled the air in the chimney is made specifically lighter and is forced out on the principle of flotation (**93**). When the temperature of the air is raised one degree F. its volume is increased $\frac{1}{491}$ of its original volume, so that if air enters a stove at 70° F. and has its temperature raised to 234° F. its volume would be increased one-third and hence its weight diminished in the same proportion, and the relative weights of air per cubic foot inside and outside the chimney would be as two to three. When these conditions exist, it is evident that the higher the chimney is the greater will be the difference in the weight of the two columns of air and the stronger the draught. When the chimney has its top considerably extended above the surface it is placed in a region of more rapidly moving air currents and the draft is made stronger on this account also.

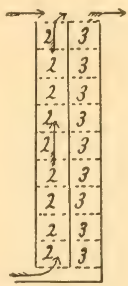


Fig. 28.

118. Transparency to Ether Waves.— When the hand is placed near a pane of glass, through which the sun is shining, the ether waves falling upon the hand are absorbed and so increase the molecular motion of the skin, raising its temperature. The hand, in turn, sends out ether waves toward the sun, but they are of the long sort and cannot pass through the glass, but are reflected back again upon the hand and join with those coming from the sun to raise the temperature to a still higher point. The glass is *transparent* to the short waves coming from the sun but opaque to the long ones into which they have been transformed in the hand.

This is the principle upon which the hot-bed is constructed, which is practically an energy trap, allowing it to enter from the sun and then preventing its ready escape.

On the same principle, too, large windows in the south side of dwelling-houses, especially if they are double, contribute a very large amount of heat toward warming the room in winter, and are really a great saving of fuel, besides contributing so much to healthfulness. The amount of heat which may enter a house in this manner during the winter is much larger than can enter it in summer, because in winter the sun shines more perpendicularly upon the windows, which has the effect of making them larger, as explained in **167.**

Our atmosphere acts practically in the same manner toward the energy received from the sun and that radiated back again by the earth. It is highly transparent to the first and very opaque to the last. Clouds, fog and smoke are still more opaque to terrestrial radiations, and this is why frosts on a cranberry marsh or strawberry bed may sometimes be prevented by producing a cloud of smoke over it.

119. Temperature.— The temperature of a molecule is an expression of the amount of energy it contains, and all molecules having the same temperatures are assumed to possess the same amounts of energy of motion. When the temperature of a given body is doubled its energy of molecular motion is doubled. Could the molecules of a body be brought entirely to rest, its temperature would be *absolute zero*, but this is a condition of things very difficult if not practically impossible to reach.

120. Measurement of Temperature.— The common method of measuring temperature is by noting the changes in volume of a body which are associated with changes in its temperature. The material of a thermometer may be either solid, liquid or gaseous, and all three types are in use. For ordinary purposes the mercurial thermometers are the best. The mercury expands more regularly than most other available liquids, thus making the graduation of the stem simple; it boils at a high and freezes at a low temperature; it can be readily seen and it responds quickly.

The sensitiveness of the thermometer depends upon the relative diameters of the bulb and tube; the finer the bore of the tube and the larger the bulb the longer will be each degree. Too large a bulb is objectionable because a longer time is required for it to acquire the temperature of the body whose temperature is desired, and too fine a bore has the objection of not being readily seen. The long cylindrical bulbs are better than the spherical ones because they present a larger surface and therefore respond more quickly, reaching a condition of rest sooner.

121. Testing a Thermometer.—The bulbs of most thermometers shrink after they are made, and if the graduation has been done before the shrinkage has occurred the reading of the thermometer will be found too high or will ultimately become so. To see whether the thermometer is correct, in this regard, it should be immersed in melting snow or crushed ice, from which the water formed by melting may readily drain away, and allowed to remain until the mercury becomes stationary.

If the thermometer is one of the dairy types or has the bulb exposed, its correctness at blood heat may be determined by placing the bulb under the tongue and keeping the mouth closed over it for about one minute, reading the temperature while the bulb is yet in the mouth. If the person is well the thermometer should indicate about 98.8° F.

It is rarely true that the diameter of the tube of the thermometer stem is uniform throughout, there being a general tendency for the diameter to increase from one end to the other. If the irregularity of the tube is large, it may be correct at the freezing and boiling points and yet incorrect at intermediate points. If the tube grows larger from the bulb the same amount of expansion in the bulb will cover a shorter distance on the scale, and vice versa. Large inequalities in the tube may be detected by jarring the thermometer so as to separate a short column of the mercury, say three-fourths of an inch, and carefully measuring its length by divisions of the scale in different portions of the stem; if there is a large variation the length of the column separated will vary as it is moved from place to place.

122. Kinds of Thermometer Scales.— There are two scales used in this country, the Fahrenheit and Centigrade. The first places the freezing point of water at 32°, and the boiling point at 212°, the second at 0° and 100° respectively. The Fahrenheit scale, between 32° and 212°, is divided into one hundred and eighty divisions called degrees, while for the Centigrade scale the number of divisions is just one hundred. This being true,

$$180° \text{ Fahr.} = 100° \text{ Centigrade}$$

$$\text{and } 1° \text{ F.} = \frac{100}{180} = \frac{5°}{9} \text{ C.}$$

$$\text{and } 1° \text{ C.} = \frac{180}{100} = \frac{9°}{5} \text{ F.}$$

To convert the readings of a Fahrenheit scale into Centigrade degrees find the number of Fahrenheit degrees from the freezing point and multiply this by $\frac{5}{9}$.

$$\text{No. of degrees F. from freezing } x \frac{5}{9} = \text{No. degrees C.}$$

To convert Centigrade degrees into degrees Fahrenheit multiply the number of degrees by $\frac{9}{5}$ and the result will be the number of degrees F. above or below 32° F.

$$\text{No. of degrees C. } x \frac{9}{5} = \text{No. of degrees F. above or below } 32° \text{ F.}$$

123. The Heat Unit.— It requires sixteen times as much heat to raise the temperature of a pound of hydrogen one degree as it does a pound of oxygen, and other ratios are found to exist when other substances are taken. This makes it necessary to select a certain substance as a standard when a unit of heat is desired. Water is taken as the standard and one heat unit is the amount necessary to raise a pound of water from 32° F. to 33° F.

124. Specific Heat.—When the amount of heat which will raise the temperature of a pound of water from 32° F. to 33° F. is applied to a pound of dry sand it will have its temperature raised through about 10° F. (Oelmer), or the same heat would raise the temperature of ten pounds of sand one degree, and the *specific heat* of sand is said to be .1, that of water being 1. With the exception of hydrogen, water possesses the highest specific heat known, and this means that it warms more slowly than do other substances; but the reverse is also true, and when once heated it cools more slowly or gives out a larger amount of heat. This is why large bodies of water make the winters of the lands adjacent to them warmer and the summers cooler.

125. The Specific Heat of Soils.—Different soils, like other substances, have different specific heats, and hence warm at different rates under the same sunshine, and it is on account of this fact, in part, that one soil is warmer than another. In the following table are given the number of heat units necessary to heat one hundred pounds of water and of varieties of soils from 32° to 33° F., and the temperature each would have after one hundred heat units had been applied to them at a temperature of 32° F.

TABLE OF SPECIFIC HEAT OF DRY SOILS.

	No. of heat units required to raise 100 lbs. from 32° F. to 33° F.	Temperature of 100 lbs. after the application of 100 heat units.
	Heat units.	*Degrees F.*
Water	100.00	33.00
Moor earth	22.15	36.51
Humus	20.86	36.79
Sandy humus	14.14	39.07
Loam rich in humus	16.62	38.02
Clayey humus	15.79	38.33
Loam	14.96	38.68
Pure clay	13.73	39.28
Sand	10.08	41.92
Pure chalk	18.48	37.41

These figures do not, in themselves, indicate the actual differences in temperature the several soils named would show under natural conditions because they are not only never perfectly dry but they have different capacities for holding water, and they differ also in their specific gravities, so that one hundred pounds of one soil covers more surface, at a given depth, than another one does. We have not yet the data needed for an exact comparison, by volume, of the specific heat of soils. The higher the per cent. of water any soil contains the more heat will be required to raise its temperature one degree; so, too, the heavier the soil is per cubic foot the more heat will be required to raise its temperature a given number of degrees. Sand has a less capacity for water than most other soils and is, on this account, naturally warmer, yet its higher specific gravity tends to make it colder than other soils. A cubic foot of dry sand weighs about one hundred and six pounds, while one of clay loam is only about seventy pounds. Saturated sand will contain, in the field, only about eighteen per cent. of water, while the clay loam may have as high as thirty-three per cent. Below are given the number of degrees one hundred heat units will raise the temperature of a cubic foot of sand and of clay loam when each is saturated with water, half saturated and dry.

	Saturated.	*Half saturated.*	*Dry.*
Sand	3.4° F.	5° F.	9.92° F.
Clay loam	2.98° F.	4.49° F.	6.02° F.
Difference	.42° F.	.51° F.	3.9° F.

It is thus seen that the greater weight of the sand, per unit volume, tends to offset the greater amount of water held by the clay, giving the two a more nearly equal temperature than they would otherwise possess. It will also be seen that the difference in the per cent. of moisture a soil may contain makes a relatively larger difference in the change in temperature a given amount of heat absorbed will produce. This is one reason why a well-drained soil is warmer than a similar one not so drained.

126. "Latent Heat."— When heat is applied to ice at a temperature of 32° F. its temperature does not rise until the melting is completed, the whole energy applied being expended upon the molecules in moving them into new relative positions against the force of cohesion which binds them together in the crystalline arrangement of the ice. The amount of heat required to melt a pound of ice whose temperature is 32° F. is, in round numbers, one hundred and forty-two units, or enough to raise the temperature of one hundred and forty-two pounds of water from 32° to 33° F. This fact may be demonstrated approximately as follows:

Take equal weights of water at 32° F. and at 212° F. and mix them. The two weights of water will then be found to possess a temperature nearly equal to

$$\frac{212^\circ+32^\circ}{2}=122^\circ \text{ F.}$$

If, on the other hand, equal weights of water at 212° F. and dry ice at 32° are placed together and the ice allowed to melt, the resulting water will be found to have a temperature of 51° F. The water has had its temperature lowered

$$212^\circ-51^\circ=161^\circ \text{ F.}$$

while the ice has had its temperature raised only

$$51^\circ-32^\circ=19^\circ \text{ F.}$$

Now if one pound each of ice and water were taken for the experiment it is evident that the number of heat units consumed in melting the ice would be

$$161-19=142 \text{ heat units.}$$

When water has been raised to the boiling point no further increase of temperature can be effected so long as the pressure upon it remains constant, the whole amount of heat energy being now expended in converting the water into steam at the same temperature.

If a pound of steam at 212° F. be condensed in 5.37 pounds of water at 32° F. there will then be 6.37 pounds of water, having a temperature of nearly 212° F. The pound of steam in being converted into water has heated 5.37 pounds of water through

$$212^\circ-32^\circ=180^\circ \text{ F.}$$

without having its temperature appreciably lowered. The molecular energy of the one pound of steam which was absorbed by the 5.37 pounds of water was therefore

$$180 \times 5.37=966.6 \text{ heat units.}$$

This large amount of molecular energy in steam explains why a scald from steam is so much more severe than one from boiling water, and also why so small a quantity of steam, by weight, is required to boil a barrel of potatoes or to cook a barrel of other feed.

127. Evaporation Cools the Soil.— We have seen that one pound of steam in condensing into water generates 966.6 heat units, and the reverse statement is also true, namely, to convert a pound of water into the gaseous state, under the mean atmospheric pressure, requires the absorption, by that pound, of 966.6 heat units. When one pound of water disappears from a cubic foot of soil by evaporation, it carries with it heat enough to lower its temperature, if saturated sand, 32.8° F.; and if saturated clay loam, 28.8° F.

To dry saturated sandy soil until it contains one-half of its maximum amount of water requires the evaporation of about 9.5 pounds to the square foot of soil surface when this drying extends to a depth of one foot, while the similar drying of clay loam requires the evaporation of 11.5 pounds, and

$$11.5-9.5=2 \text{ lbs.}$$

or the amount of evaporation which must take place in the clay loam to bring it to the same degree of dryness as the sandy soil. But to evaporate two pounds of water requires

$$966.6 \times 2=1933.2 \text{ heat units,}$$

and this, if withdrawn directly from a cubic foot of saturated clay loam, would lower its temperature 57.6° F. Here is one of the chief reasons why a wet soil is cold.

That the evaporation of water from a body does lower its temperature may be easily proved by covering the bulb of a thermometer with a close fitting layer of dry muslin, noting the temperature. If the muslin be now wet, with water having the temperature noted, and the thermometer rapidly whirled in a drying atmosphere its temperature will rapidly fall, owing to the withdrawal of heat from the bulb by the evaporation of water from the muslin.

128. Regulation of Animal Temperatures.— All of our domestic animals require the internal temperature of their bodies to be maintained constantly at a point varying only a little from 100° F., and this necessity requires provisions both for heating the body and cooling it. The cooling of the body is accomplished by the evaporation of perspiration from the skin and the amount of perspiration is under the control of the nervous system. When the temperature becomes too high, because of increased action on the part of the animal, or in consequence of a high external temperature, the sweat glands are stimulated to greater action and water is poured out upon the evaporating surfaces and the surplus heat is rapidly carried away; each pound evaporated by heat from the animal withdrawing about 966.6 heat units.

129. Bad Effects of Cold Rains and Wet Snows on Domestic Animals.—When cattle, horses and sheep are left out in the cold rains of our climate the evaporation of the large amount of water which lodges upon the bodies, and especially in the long wool of sheep, creates a great demand upon the animals to evaporate this water. The theoretical fuel value of one pound of beef fat is 16,331 heat units, and that of average milk is 1,148 heat units. A pound of beef fat may therefore evaporate

$$\frac{16331}{966.6}=16.8 \text{ lbs. of water,}$$

and a pound of average cow's milk

$$\frac{1148}{966.6}=1.18 \text{ lbs. of water.}$$

On this basis, if a cow evaporates from her body four pounds of rain she must expend the equivalent of the solids of 3.39 pounds of milk.

A wet snow-storm is often worse for animals to be out in than a rain-storm, because in this case, the snow requires melting as well as evaporating, and the number of heat units per pound of snow is

$$142.65+966.6=1109.25 \text{ heat units,}$$

and the heat value of a pound of milk is barely sufficient to melt and evaporate a pound of snow.

130. Cooling Milk with Ice and with Cold Water.—If it is desired to cool one hundred pounds of milk from 80° F. down to 40° F. it is practically impossible to do so with water in the summer season in Wisconsin. It is difficult even to cool it as low as 48° F., for most of the well and spring water has a temperature above 45° F. and much of it is above 50° F. If lower temperatures than 48° F. are desired during the warm season some other means must be resorted to. Since it requires one hundred and forty-two heat units to melt a pound of ice, one pound is capable of cooling from 80° F. to 40° F.

$$\frac{142+8}{40}=3.75 \text{ lbs. of milk,}$$

supposing the specific heat of milk to be the same as that of water, which is not quite true. To cool one hundred pounds of milk from 80° F. to 40° F. will require, therefore, about

$$\frac{100}{3.75}=26\tfrac{2}{3} \text{ lbs. of ice,}$$

supposing it to be used wholly in cooling the milk.

If the water has a temperature above 40° F., before the milk and ice are placed in it, there will be required enough more ice to cool the water down to the temperature desired for the milk.

The greatest economy in the use of ice will be secured, therefore, when the creamer contains just as little water as will cover the cans and give the needed space for the ice, and when the walls of the creamer are made of so poor a conductor of heat as to admit as little as possible from without.

131. Washing with Snow or Ice.— When ice or snow are used in winter for washing purposes there is a large loss of heat incurred in simply melting the ice and raising the temperature of the water from 32° F. up to 45° F., the temperature it may have in any well protected cistern. To melt a pound of ice and raise its temperature to 45° F. will require

$$142+13=155 \text{ heat units.}$$

If three hundred pounds of water are required for a washing then the lost heat will be

$$300 \times 155=46500 \text{ heat units.}$$

The fuel value of one pound of water-free, non-resinous wood, such as oak or maple, has been found to be 15,873 heat units; that of ordinarily dry wood, not sheltered, containing 20 per cent. of water, is 12,272 heat units. At this latter value it will require, supposing 50 per cent. of the fuel value to be utilized in melting the ice and heating the water,

$$\frac{2 \times 46500}{12272}=7.58 \text{ lbs. of wood}$$

more than would be needed to do the same washing with water at 45° F.; and if seventeen such washings are done during the winter the total cost for fuel would be the value of

$$17 \times 7.58 = 128 \text{ lbs. of wood,}$$

to say nothing of the expense of getting the snow or ice and the unhealthfulness of handling it.

132. Burning Green or Wet Wood.— Whatever water wood or other fuel may contain when it is placed in the stove, so much of the fuel as is required to evaporate this water must be so expended and is prevented from doing work outside of the stove. We have seen, **131,** that when wood contains 20 per cent. of water there is required

$$15873 - 12272 = 3601 \text{ heat units}$$

per pound of wood to evaporate the water contained, which is 22.7 per cent. of the total value. Wood, after being in a rain of several days, contains more water than this, and green wood much more, sometimes as high as 50 per cent., while well-seasoned sheltered wood may contain less than half that amount.

It is frequently urged that when some green or wet wood is burned with that which is dry there is a saving of fuel. There is some truth in this, especially in stoves having too strong a draught and too direct a connection with the chimney and if the radiating surface is small or poor. The evaporation of the water prevents so high a temperature from occurring in the stove, which makes the draught less strong, and this gives more time for the heat to escape from the stove before reaching the chimney, and hence less is lost in this way. Then as the fire burns more slowly there is not the overheating of the stove, at times, which may occur with lack of care when very dry wood is used, and a considerable saving occurs in this way. These statements apply more particularly to heating stoves than to cooking stoves. Dry wood is best for the kitchen stove under most circumstances, the slower fire being secured when needed by using larger sticks and by controlling the draft.

133. High Winter Temperatures Associated with Snow Storms.— "It is too cold to snow" is a common saying, but the truth is it cannot snow and remain very cold.

Speaking in approximate terms, when a pound of water in the form of aqueous vapor in the air is converted into snow there is liberated

$$966.6 + 142 = 1108.6 \text{ heat units,}$$

and, as the specific heat of dry air is only .2375, one heat unit will raise the temperature of one pound of air through

$$\frac{1}{.2375} = 4.21^\circ \text{ F.}$$

and 4.21 pounds of air through 1° F. This being true, the freezing of one pound of aqueous vapor will liberate heat enough to warm through 1° F.

$$1108.6 \times 4.21 \text{ pounds} = 4667.2 \text{ pounds of air,}$$

and as water at 32° F. is 773.2 times heavier than air at the same temperature, the number of cubic feet of air raised 1° F. must be

$$\frac{4667.2}{\frac{62.417}{773.2}} = 57815.6 \text{ cu. ft. of air,}$$

which is equivalent to 5781.56 cubic feet raised 10° and to 1806 cubic feet raised from 0° F. to 32° F. When a snow fall of four to six inches occurs, over a large area, there is, therefore, a very large volume of air heated by it.

PROTECTION AGAINST LIGHTNING.

134. Nature of Electricity.— No very clear statement is yet possible in regard to the real nature of either electricity or magnetism, but the strongest evidence points to the conclusion that they are manifestations due to some action of the all-pervading ether which we have seen, **113,** is the medium through which energy generated at the sun's surface reaches the earth. In the battery, on the telegraph line, energy is generated by the chemical action there taking place and, by some action not yet clearly seen, the ether pervading the space between and surrounding the molecules of the telegraph wire conveys this energy to the distant stations, where it is absorbed by the receiving instruments and converted into mechanical motions which record or indicate the messages sent. In some manner the molecules of a conducting wire prevent the escape of energy to the outside ether as the walls of a speaking tube confine the sound waves developed in them, preventing them from being dissipated in the surrounding air and allowing them to travel to the end only slightly enfeebled.

When a glass rod is rubbed with a piece of silk or fur the mechanical action develops a state in the ether of the rod which is shown by the ability of the rod, in this condition, to attract light objects to it. When a person speaks in front of a telephone the sound waves produced by the vibration of his vocal cords set the metal plate, near the end of the telephone magnet, swinging in unison with the vocal cords, and the approaches and recessions of this plate so disturb the ether of the magnet as to cause it to take up a part of the energy of the vibrating plate and then to transmit it to the ether of the wire wrapped about the magnet and leading to the receiving station, where, by another of those wonderful yet universal transformations of energy, the action is reversed and the mechanical swing of the plate in the receiving telephone gives back the words which set up the action at the sending station.

135. Atmospheric Electricity.— What the origin is of the intense electrical manifestations associated with thunder

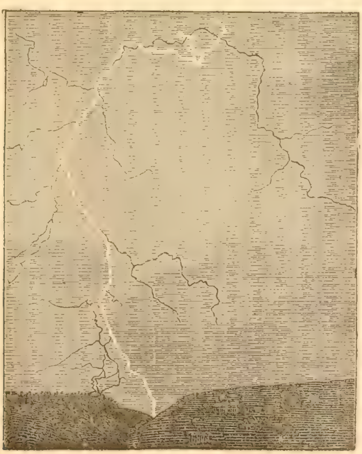


Fig. 29.

storms as yet lacks positive demonstration, but the close resemblances of these manifestations to the electrical manifestations developed by friction, when combined with the fact that the strongest atmospheric electrical displays are associated with the most violent air movements where rain or hail is present, has led to a general belief that this electricity owes its origin to the friction of the air currents upon the condensed moisture they are carrying. Fig. 29 represents the general character of an electrical discharge in the atmosphere.

136. Electrical Induction.— When a body, which has become charged with electricity, is brought near another body which has not been electrified it exerts an influence upon that body inducing electricity in it, and if the charge is sufficiently intense and the distance is not too great the electricity will break across from one body to the other, and the act may be accompanied by a flash of light and a report.

137. Positive and Negative Electricity.— It is impossible to throw a stone into water, making a depression at any point, without raising a ridge around it which is equal in magnitude to the depression, but extending in the opposite direction. When these two opposite phases are developed they tend to come together, and the tendency is stronger in proportion as the waves are higher. Something analogous to this state of things seems to occur whenever and wherever electricity is generated. There appears always to be engendered two equal and opposite phases which tend to run together and obliterate each other unless prevented from doing so. The one phase is called *positive* and the other *negative* electricity.

138. Conductors and Non-conductors of Electricity.— There is a great difference in the ability of different substances to convey electricity from one place to another; those which convey electricity readily are called conductors, and those which convey it poorly or not at all are called poor conductors or non-conductors. The metals generally are among the best conductors, and silver and copper are the best of these. Glass, gutta percha and dry air are among the poorest conductors.

139. Discharges from a Point.— When a body becomes charged with electricity the charge manifests itself only on the outside surface. If the body is a sphere the intensity of the charge will be uniform at all portions of the surface. If, however, the body is conical or has points upon it the charge will be most intense at the points, and if a discharge takes place it will occur first from the points, and it is this fact which has led to the placing of points on lightning-rods.

140. When an Object May be Struck by Lightning. When a cloud becomes so heavily charged that the air between it and an adjacent cloud or an object on the ground, in which it has induced the opposite kind of electricity, is no longer able to prevent the electricity from breaking through, a discharge or stroke occurs. Usually the nearer the charged cloud approaches an object the more intense will be the charge induced by the cloud in the body approached and the greater will be the chances of a stroke. The intensity of attraction increases as the square of the distance decreases, and this is why, when other conditions are the same, elevated objects, like buildings, are more liable to a stroke than those which are lower.

Buildings standing upon wet ground are more liable to a stroke than buildings in other respects similar but standing upon dry ground, the greater danger coming from the possibility of a stronger charge being induced upon the house in consequence of the better conduction of the wet soil. Large trees near buildings have a tendency to prevent strokes.

141. The Function of a Lightning-rod.— Lightning-rods have two functions to perform, the first and chief one being to discharge quietly into the air above, the electricity which may be induced upon a building as rapidly as it accumulates, and thus *prevent* a stroke from occurring; and second, in case a stroke is inevitable, to diminish its intensity and convey to the ground quietly as much of the discharge as possible, thus reducing the damage to a minimum.

142. Do Lightning-rods Afford Complete Protection?— There is now a general agreement among physicists that properly constructed and mounted lightning rods furnish a large protection to buildings; they are divided in opinion, however, as to whether complete protection is possible. The rod may be called upon to protect against discharges under two conditions: first, where a heavily-charged cloud comes slowly over the rod, giving it time to discharge the induced electricity and thus prevent an accumulation; and second, where an uncharged cloud chances to be over a rod when it instantaneously becomes charged from some other cloud. When this occurs it is claimed by some that the rod has insufficient time to afford any material protection, and hence that it is hopeless to think of protecting completely against this class of cases.

143. Essential Features of a Lightning-rod.— For a number of years past there has been a fairly unanimous agreement in regard to the essential points of a lightning rod, but some new discoveries in regard to the conduction of rapidly alternating currents, and in regard to electrical inertia, has led to a divergence again upon some points. It may be said that practically all are agreed that:

1. The rod should be of good conducting material, continuous throughout, terminating in several points above, and well connected with permanent moisture below the structure in the ground.

2. The rod should be in good connection with the building, especially with metal roof and gutters, and should be carried as high as the highest point of the structure to be protected.

3. The points need not be very fine, but should be coated with some metal which will not rust.

4. An iron rod, everything considered, is better and cheaper than one of copper, provided it is galvanized and of sufficient size.

The fundamental point of disagreement at present is in regard to the form of the rod: some claiming that if a sufficient area of cross-section is given the shape is immaterial so far as conducting ability is concerned, the solid round rod being the cheapest and most easily protected from rust; others maintain that the larger the surface the rod presents the greater will be its conducting power and that the flat ribbon is the cheapest and best.

The first view is founded on the fact that, for steady currents, the conducting power is directly proportional to the area of the cross-section. The second view is founded upon what now appears to be the fact that very rapidly alternating currents travel only through an extremely thin layer of the surface of the conductor, and what also appears to be the fact, that lightning discharges are a series of extremely rapid alternating currents. The settling of this point of dispute is likely to require the testimony of actual and extended practical tests with both forms of rods.

144. Danger to Stock from Wire Fences.— The introduction of wire fences has to some extent increased the danger from lightning to stock in pastures, owing to the tendency of the wires to become charged, and then give off side sparks to the animals standing near. The danger is less from the barbed wire than from the plain, and the danger from both may be lessened by connecting the several wires with the ground by means of other wires tacked to the sides of the posts, the lower end being turned under the point of the post when set. The staples should be driven astride the two wires so as to hold them in close contact. It is not possible to say just how close together these discharging wires should be placed, but probably not nearer than 15 to 20 rods.

SOIL PHYSICS.

145. Nature of Soil.— The basis of all soil consists of the undissolved remnants of the underlying rocks. Associated with these remnants there is always a varying per cent. of organic matter, resulting from the decay of vegetable and animal remains; a certain amount of dust particles brought from varying distances by the winds, or washed down by raindrops and snowflakes which have formed about those floating high above the earth's surface; and a considerable amount of saline substances brought constantly to the surface by the upward movement of capillary water, and left deposited when the water evaporates.

146. Origin of Soils.— All soils owe their origin to the processes and agencies of rock destruction which have been and still are taking place in three chief ways:

1. Many rocks have been mechanically broken into larger or smaller fragments.

2. Other rocks have had their molecules separated by simple solution as salt is dissolved by water, or the molecules have first been changed chemically and then dissolved.

3. Still other rocks have had some of their mineral constituents dissolved out, leaving the remainder as an incoherent mass of fragments. In Fig. 30 are shown the stages of transition from the underlying rock to the soil above as it occurs on lime-

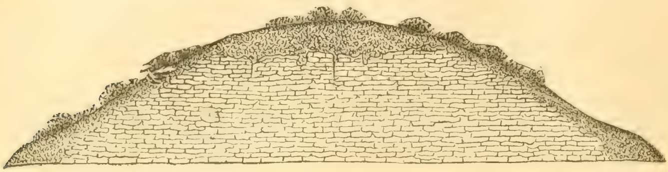


Fig. 30.

stone hills, while Fig. 31 shows the same facts for a more level limestone surface. On examining the rocks of almost any

Fig. 31.

quarry they are found to be divided into blocks of varying sizes by fissures or breaks which owe their origin to a general shrinkage of the rocks and to movements of the earth's surface layers. These are the first steps in soil formation, and are plainly shown in Figs. 32 and 33. They exert a great influence in rock destruction and soil formation by furnishing easy access for water and the roots of trees to their interior, where the first by freezing and the second by growth expand and break the blocks into smaller fragments. Moving ice, in the form of glaciers, has done a vast amount of rock grinding, the present soil of all except the southwestern portion of our own state being the altered surface of a thick mantle of boulders, gravel, sand and clay formed, transported and spread out by glacial action and the waters from the melting ice. Then there are many animals which have contributed largely to this rock grinding and soil formation. Darwin, through a long and careful study, reached the conclusion that in many parts of England earth-worms pass more than 10 tons of dry earth per acre through their bodies annually, and that the grains of

Fig. 32.

Fort Danger, Wis. From a Photograph. After Chamberlin.

Fig. 33.

Bee Bluff, Wis. From a Photograph. After Chamberlin.

sand and bits of flint in these earths are partially worn to fine silt by the muscular action of the gizzards of these animals;

Fig. 34.

A tower-like casting ejected by a species of earthworm, from the Botanic Garden, Calcutta: of natural size, engraved from a photograph. After Darwin.

this same work is going on in our own soils, where the holes bored by angle-worms represent the volume of dirt they have passed through their bodies. All seed-eating birds take into their gizzards and wear out annually large quantities of sand and gravel, after the manner of our domestic fowls.

The other two methods of soil formation depend mainly, though not wholly, upon chemical changes wrought in the rock minerals. Pure water has the power to dissolve, without chemical change, greater or less quantities of most rock minerals which are brought to the surface by capillary action and become fine grains in the surface soil; but the larger part of this work is brought about by the action of water in conjunction with oxygen, carbonic, nitric, sulphuric, humic and other acids which it carries down into the rocks, where the work of solution goes on rapidly. Mr. T. M. Reade has estimated that the Mississippi alone carries to the sea annually 150,000,000 tons of rock in solution, and yet a large part of the water which enters the soil is brought back again to the surface and evaporated, leaving the materials it has dissolved as a contribution to agriculture.

147. Soil-convection.— On the surface of a lake the water which is at the top one moment is at another below the surface, the molecules changing position continually by convection currents due to changes of temperature. There is a movement somewhat analogous to this taking place in every fertile soil, though the movements are less rapid and are due to different causes. Earthworms, ants, crayfish, gophers and various other burrowing animals each season bring large amounts of the finer portions of the lower soil and subsoil to the surface, forming systems of galleries with openings leading out to the free air at various places. Each heavy rain, especially during the fall and spring, washes the finer surface soil into these galleries, filling them up, and new excavations are again made, thus keeping up a slow, but nevertheless a certain circulation, which in some of its effects is like the fall and spring plowing, but much of it extending to far greater depths, the angleworms, ants and crayfish often going down from three to five or more feet during dry seasons. Darwin's observations have shown that this rotation of soil, which he attributes largely to the action of earthworms, tends to bury coarse objects, like flints, lying on the surface, as time passes, and in Fig. 35 is represented one of these cases as cited by him.

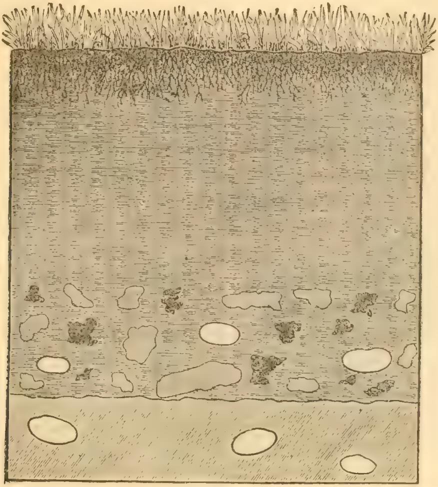


Fig. 35.

Section reduced to half natural scale, of the vegetable mould in a field drained and reclaimed 15 years before. Showing turf, vegetable mould without stones, mould with fragments of burnt marl, coal cinders and quartz pebbles; and subsoil of black peaty sand with quartz pebbles. After Darwin.

148. Soil Removal.—Pitted against these processes of growth there is a powerful and universal set of agencies constantly operating everywhere to transport from higher to lower levels and from the land to the sea the surface soils, and the magnitude of this action has been estimated at not far from one foot each 3,000 years as an average for the whole land surface, and hence the superficial and exhausted soils are being slowly removed and replaced by new soil originating from the products of rock decay, and brought to the surface by capillary action and that of burrowing animals generally. The absolute amount of soil removal can be appreciated when it is understood that the summits of the bluffs represented in Figs. 36 and 37 show the general level of the surrounding lower land at a former time and that, at times intervening between the present and that earlier period, vegetation has grown on soil occupying all the levels between the two shown in the engravings.

Fig. 36.

[Giant's Castle, near Camp Douglas, Wis. From a Photograph. After Chamberlin.

Fig. 37.

Pillar Rock, Wis. From a Photograph. After Chamberlin.

149. Surface Soil.—Soils proper comprise the surface five to ten inches of fields and woodlands generally. Oftentimes the depth of the true soil may be less than five inches, and then again it may exceed a depth of ten inches by varying amounts. It is the portion which has been longest and most completely exposed to the disintegrating and solvent action of rock-destroying agencies, and as a result of this fact it contains a smaller per cent. of the soluble minerals used by plants than the less altered subsoil below. Its chief ingredients are:

1. Sand.
2. Clay.
3. Humus.

} Composing about 90 to 95% of the dry weight;

which are commingled in varying proportions, giving rise to different varieties according as one or another of these ingredients predominates. The true soil, on account of its more complete aeration and its higher temperature, is the chief laboratory in which the nitrogen compounds for plant food are elaborated.

150. Kinds of Surface Soil.— For practical purposes soils are variously classified. When reference is had to the ease or difficulty of working the soil it is spoken of as

1. Light, or
2. Heavy;

but these terms have no significance as regards actual weights; for a sandy soil is spoken of as light, and yet it is the heaviest of all soils, bulk for bulk. The greater weight of the sandy soil is due more to the lack of large cavities which are found in the clayey soils, than to the higher specific gravity of the soil constituents. It is the greater adhesiveness of the clayey soils which causes the plow, hoe or harrow to move with greater difficulty through them.

When reference is made to the temperature of soils, at the same season, they are spoken of as

1. Warm, or
2. Cold,

according as the temperature of the soil is relatively high or low. In this case the soils containing the greatest amount of water are, when other conditions are similar, the colder on account of the high specific heat, **125,** of the water.

When the chief ingredients of soil are the basis of distinction they are frequently classified as

	Sand. *Per cent.*	Clay. *Per cent.*	Humus. *Per cent.*
1. Sandy soil, containing....................	80 to 90	8 to 10	1 to 3
2. Sandy loam, "	60 to 80	10 to 25	3 to 6
3. Loam, "	25 to 60	60 to 25	3 to 8
4. Clayey loam, "	10 to 25	60 to 80	3 to 8
5. Clayey soil, "	8 to 15	70 to 80	3 to 6

In peaty soil, or those of our low marshes and swamps, there is often as high as 22 to 30 per cent. of humus. It should be kept in mind that the sand, clay and humus of soils are not plant food proper except in a small degree; they are, except a part of the humus, what is left after the plant food is removed. They serve, however, an important purpose in furnishing a proper feeding ground for the roots and a means of supporting plants in their upright attitude.

151. Subsoil.— The subsoil is the real source of the natural mineral constituents of plant food, while at the same time it acts as a reservoir for water which is delivered at the surface by capillary action or held within its mass until the penetrating roots remove it. The depth to which roots penetrate the subsoil is really great, and I believe the depth is determined primarily by the water content of the soil, the roots traveling farther when the supply is scanty. Wheat roots are recorded as observed at a depth of seven feet in Rhenish subsoil of a sandy loam. Corn roots with us commonly reach a depth of three feet and often exceed four. It would appear, therefore, aside from the fact that the subsoil is the parent of the true soil and that it acts as a water reservoir, that the chemical composition and physical characters of the subsoil may determine in a large measure the productiveness of land, unless it should be determined by future investigations that the deep-running roots are simply water-gatherers.

152. Variation in Composition of Subsoils.— There is a marked difference in the composition of those subsoils of Wisconsin which are simply the residuary products of the decay of rocks in place, such as those represented in Figs. 30 and 31, and those which owe their origin to glacial grinding and mixing. This difference is clearly brought out in the table given below, which is compiled from analyses of typical samples of residuary subsoils from southwest Wisconsin and of glacial subsoils from the vicinity of Milwaukee as given by Chamberlin & Salisbury in the Sixth Annual Report of the United States Geological Survey:

	Residuary Subsoils.	**Glacial Subsoils.**	**Difference.**
	Per cent.	*Per cent.*	*Per cent.*
Silica, SiO_2	55.73	44.52	−11.21
Alumina, Al_2O_3	18.16	8.01	−10.15
Lime, CaO	.99	13.74	+12.75
Magnesia, MgO	1.11	7.42	+6.31
Potash, K_2O	1.24	2.48	+1.24
Phosphorus, P_2O_5	.03	.09	+.06
Carbon Dioxide, CO_2	.35	17.11	+16.76
Iron, Fe_2O_3	10.57	2.68	−7.89
Organic matter	9.86	2.33	−7.53
Other substances	1.37	1.95	+.58

It will be seen that the insoluble sand, clay and iron compounds predominate in the residuary subsoils, while the lime, magnesia, potash and phosphorus compounds are in excess in the glacial subsoils, and this at first thought seems strange when it is remembered that the residuary soils are derived directly from magnesium limestones and that two of the four samples giving the average were taken in contact with the limestone itself, but these soils are what is left after the soluble carbonates are leached away.

The photo-engraving of a relief map of Wisconsin, Fig. 38, showing the glaciated and non-glaciated areas of the state, also

Fig. 38.

Photo-engraving of a relief map of Wisconsin, showing the glaciated and non-glaciated areas of the state.

shows, in general, the distribution of the glacial and residuary subsoils. The area of rugged topography in the west and southwest of the state is the region covered by the residuary subsoils. It should not be inferred, however, that the composition of all of our glacial subsoils is fairly represented by the samples from the vicinity of Milwaukee, for in the northern portion of the state there were no large areas of limestone to be ground down by the ice to contribute the large amounts of lime and magnesia found in the locality cited.

153. Size of Soil Particles.— The size of soil particles has very much to do with the value of a soil, this quality determining, in some measure, its water capacity, its retentiveness of fertilizers, its drainage, its aeration and the way in which the soil works. In general the relative number of large grains as compared with the smaller ones is greater at the surface than at some depth below; this difference is due largely to the tendency of rain to pick up and carry away or to carry downward by percolation the finer particles.

Chamberlin and Salisbury, as a result of their studies bearing upon the size of soil particles constituting residuary earths, say: "Out of 158,522 measured particles from several representative localities, only 929 exceeded .005 mm in diameter. A fairly illustrative example from near the rock surface at Mt. Horeb, Wis., gave, in a single miscroscopic field, the following showing:

Particles less than .00285 mm in diameter.........................	15,152
Particles between .00285 mm and .005 mm in diameter..............	208
Particles more than .005 mm in diameter...........................	54

None of the 54 particles reached so great a diameter as .01 mm," that is, the largest of the 54 large ones had a diameter so small that 25,400 of them placed side by side would be required to span a linear inch.

Many of the soils which tend so strongly to clog the plow are of this extremely fine-grained type, and a partial explanation may be found in the minute particles wedging into the microscopic cavities due to the grain or texture of the material of the mold-board.

154. Needs of Soil Aeration.— The necessity for a considerable circulation of air in soil actively supporting vegetation is generally recognized, and the demand for this circulation is three fold:

1. To supply free oxygen to be consumed in the soil.
2. To supply free nitrogen to be consumed in the soil.
3. To remove carbon dioxide liberated in the soil.

Prominent among the demands for oxygen in the soil may be mentioned:

1. The respiration of germinating seeds.
2. The respiration of growing roots.
3. The respiration of nitric acid germs.
4. The respiration of free-nitrogen-fixing germs.
5. The respiration of manure fermenting germs.

It has been abundantly demonstrated that when oxygen is completely excluded from seeds, placed under otherwise natural conditions for germination, growth does not take place; if the germination is allowed to commence and then oxygen is withdrawn further development will cease. When the air surrounding a sprouting seed contains only $\frac{1}{32}$ of the normal amount of oxygen the germination will go on, but the rate is retarded and a sickly plant is likely to result. Experience abundantly proves that when soil bearing other than swamp vegetation is flooded with water, or even kept in an over-saturated state, the plants soon sicken and die, and this, too, when they may be in full leaf and abundantly supplied with nourishment, sunshine and warmth. The difficulty is the lack of root-breathing. Oxygen in sufficient quantity cannot reach the roots to maintain life. The plants are suffocated. This explanation is apparently disproved by the fact that seeds of various kinds may be germinated in a float of cotton resting on the surface of water, and may even be made to mature seeds if the water in which the roots are immersed is kept supplied with the proper foods in solution. The floating gardens of the Chinese, consisting of basket-work made strong enough to carry a layer of soil in which crops are matured with their roots immersed constantly in water, is another apparent disproof that wet soils kill the plants by depriving them of oxygen. The two classes of cases are, however, very different. In the cases of water culture the free water is subject to strong convection and other currents which rapidly bring the water exhausted of its free oxygen to the surface, where it becomes charged again. In the water-soaked soil, with a relatively much smaller quantity of water, all possibility of convection currents is prevented by the cohesive power of the soil, and the rate of diffusion in such cases must evidently be extremely slow, so that, viewed in this light, the two sets of cases stand in strong contrast.

The natural nitrates, so essential to fertile soils, owe their origin to a minute germ closely related to the "mother of vinegar" and called in olden times the "mother of petre." This ferment germ produces the nitric acid of soils which, after uniting with some of the bases contained in the soil, is absorbed by the plants as food. When the production of saltpetre was a considerable industry in Europe one of the conditions necessary to rapid formation was to keep the rich soil well aerated by frequent stirring and by the introduction of gratings to increase the air spaces. Oxygen is one of the essentials to the life of these important germs, and herein lies, in part at least, the advantage of cultivation and of properly drained soils.

While we have, as yet, less positive knowledge in regard to the respiratory needs of the free-nitrogen-fixing germs, now coming rapidly into recognition, there is no reason to doubt the beneficial effects of a properly aerated soil upon them.

In regard to the manure fermenting germs we have abundant proof of the need of ventilation from their action in the strong heating of the well ventilated coarse horse manure when contrasted with the absence of heating in close cow dung free from coarse litter.

Not only must oxygen and nitrogen be introduced into the soil, but the large amounts of carbon dioxide liberated by the fermenting processes and by the decomposition of the bicarbonates contained in soil-waters must be passed out in order to make room for the other gases to enter in a sufficiently concentrated form to answer the conditions of life going on there.

155. Methods of Soil Aeration.— Most field soils, when in their natural undisturbed condition and nearly saturated with water, are impervious to such air currents as the greatest differences of atmospheric pressure and temperature in a given locality can produce. It is on this account, in part, that earthworms come to the surface in such great numbers during and after heavy rains. The many perforations made by earth worms constitute so many chimneys in and out of which the air moves with every change of atmospheric pressure and temperature. Cultivation as soon as possible after rains aerates the soil at the time when it contains an abundance of moisture at the surface and is in the best possible condition for the rapid action of the niter germs, which need plenty of air, moisture and warmth.

Harrowing winter grain in the spring tends to make the aeration of the soil more perfect by breaking up the crust formed by the deposit of saline substances brought up by capillary action.

Drainage, by carrying off the water more rapidly and to a greater depth, opens the pores of the soil, making its breathing more perfect.

Strong-rooted crops, like the red clover, which send their roots deeply into the subsoil, leave it so channeled by the decay of those roots that a more perfect circulation of air is thus secured.

156. Soil Moisture.— The moisture contained in soils is of the utmost importance agriculturally, for without it all growth is impossible. Some of its chief functions may be stated as follows:

1. By its solvent power it facilitates and promotes chemical changes in the soil.
2. By its expansive power when freezing it mechanically divides the coarser soil particles into finer ones.
3. By its capillary movements it conveys food to the roots of plants.
4. By its osmotic power it transports plant food to the leaves for assimilation.
5. By the same power it conveys the assimilated food to the tissues for growth.
6. By its osmotic power it swells the seed and ruptures the seed coats preparatory to germination.
7. By the pressure it is under in the plant it gives succulent tissues much of their rigidity.
8. By its high specific heat it prevents the soil temperatures from becoming too high by day and too low during the night.

157. Amount of Water Consumed by Plants.— Hellriegel found, by experiments conducted in Prussia, that the amounts of water drawn from the soil and given to the air by various plants under good condition of growth, for each pound of dry matter produced by the crop in coming to maturity, were as stated in the table below:

NUMBER OF POUNDS OF WATER TRANSPIRED BY PLANTS IN PRODUCING ONE POUND OF DRY MATTER.

	Water.		Water.
	Lbs.		*Lbs.*
Barley	310	Horse beans	282
Summer rye	353	Peas	273
Oats	376	Red clover	310
Summer wheat	338	Buckwheat	363

This, it will be seen, is at an average rate of more than 325 tons of water for each ton of dry matter when growing under the climatic conditions of Prussia. This amount seems enormous and may perhaps be too high, but there can be no question but that the quantity is very large, and necessarily so, because practically all of the dry matter of the plant requires to be in solution when in transit to the place where it is finally deposited as a part of the structure.

The chemical analyses of nineteen natural spring and well waters from different localities in Wisconsin show the saline ingredients to constitute .0475 per cent. of their weight, or .95 pounds of solids in solution per ton. The ash in a ton of the dry matter contained in corn ensilage is about 152 pounds, and for the average spring water to yield this would require 160 tons, supposing the total saline ingredients to be used by the plant. While it is probable that soil water as it comes in contact with the roots of plants is much more highly charged than the average spring water, it is also true that not all salts held in solution contribute to the ash of plants, so that it still seems imperative to assume a large consumption of water per pound of dry matter in plants.

If we take the average of Hellriegel's results, given in the table, as applying to corn in Wisconsin, and 8,400 pounds as the average yield of dry matter per acre, about 12 inches of rain must be drawn from our soils by this crop each year, and yet this is a full third of our total mean annual rainfall. Not all the water which evaporates from a corn field during the growing season can pass through the corn, and there are eight months each year when the corn is not in the ground but evaporation goes on during all that time. To these losses must be added the water carried out of the state by rivers. Such facts should teach, in an emphatic manner, the need of adopting such methods of tillage as will tend to conserve the soil moisture.

158. Position and Attitude of the Water-Table.—The water-table is the surface of standing water in the soil. The distance the water-table lies below the surface exerts a marked influence upon the yield of crops per acre. If the water lies too close to the surface, drainage is required to secure the best yields; when the water-table lies too low, none

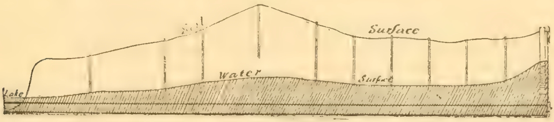


Fig. 39.

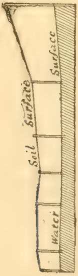


Fig. 40.

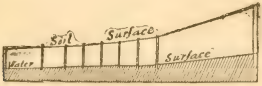


Fig. 41.

Figs. 39, 40 and 41, showing the relations of the water-table to the surface of the ground on the Experiment Farm. Figs. 39 and 41 represent north and south profiles, and Fig. 40 one extending across the other two. The vertical parallel lines represent wells. Vertical scale,—1 in.=40 ft.; horizontal scale,—1 in.=about 380 ft.

of that water is available for plant growth. Permanent ponds and lakes are continuations of the water-table above the surface of the ground, and their levels lie at varying distances below the level of the water in the ground, the water-table rising usually as the distance from these bodies of water increases and as the ground rises.

In Figs. 39 to 42 the position and attitude of the water-table is shown as it occurs on the Experiment Farm. In these cases

Fig. 42.

Showing the relation of the water-table to the surface on Picnic Point. Vertical scale, for the water-table 1 in.=4 ft., for the surface, 1 in.=8 ft.

the water stands highest under the highest ground, which appears to act simply as a reservoir in which the rains accumulate, the friction of the soil retarding the flow toward the lake.

The common belief that wells are supplied with water from adjoining lakes or rivers, the water simply filtering through the soil into them, is not generally true though it may be in some exceptional cases. Neither is it usually necessary to dig to a depth of the level of adjoining lakes before water is found. Here at Madison water is obtained in wells, in some cases, 20 feet above the level of the lakes, and the wells may not be more than 40 rods from the lake shore and sunk simply in a ridge of glacial sand and gravel lying between the two lakes.

159. Fluctuations in the Level of the Water-Table. The level of the water in the ground is not constant, but stands higher after a series of wet years and falls again with a succession of dry seasons. There is also an annual rise and fall of the water-table, the water standing lowest toward the latter part of fall or early winter and highest in the spring. In those cases where the water-table lies near the surface it is frequently raised by single heavy rains. Even changes in atmospheric pressure affect slightly the level of water in wells, causing it to rise with a falling barometer and fall with a rising barometer.

The growth of crops appears also to affect the hight of the water-table when it lies near enough the surface to come within range of root action. This effect is shown in Fig. 43. The same figure also shows to what extent the water-table fell during a growing season.

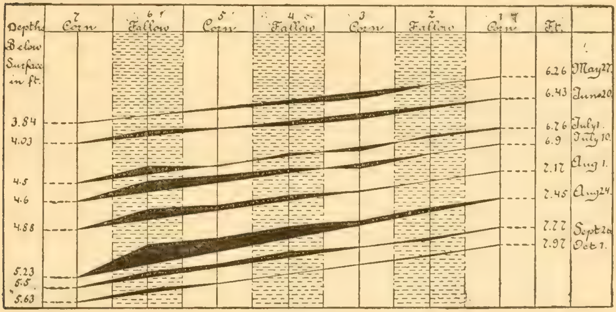


Fig. 43.

Showing changes in the surface of the water-table under alternate fallow plats and plats of growing corn. The straight lines connect the water-levels of wells 1 and 7 on the dates specified at the right, and the broken line joins the water surfaces of wells 2, 3, 4, 5 and 6 on the same dates.

160. Best Hight of the Water-Table.—It is a matter of great importance, as bearing upon all questions of land drainage, to know at just what distance below the surface of the ground the water-table should lie to interfere least, and at the same time to contribute most, to plant growth. In European cultivation it is held that the tillage of moors and bogs can only be successful when the water-table is maintained at least 3 feet below the surface in summer and 2 feet in winter. For light and gravelly soils in good condition a depth of 4 to 8 feet is held to be best for the majority of crops. The problem is manifestly a complex one which cannot be simply stated. The case must vary with the character of the soil, with the season, and with the habit of the cultivated crop, as to whether it is naturally a shallow or a deep-rooted one.

161. The Vertical Extent of Root-Feeding.—Just how deeply root-feeding may extend below the general limit of root growth must depend upon the vertical distance through which capillary action is able to pass water upward into the root zone. In the fall of 1889 it was found that clover and timothy, growing upon a rise of ground some 28 to 30 feet above the water-table, had reduced the water content of sand, at a depth of 5 feet, to 4.92 per cent. of the dry weight, when its normal capacity was about 18 per cent., and this seems to be a case of strong root-feeding to a depth of more than 5 feet.

In the table below are given the percentages of water in the soils of closely contiguous localities bearing different crops; the distance between the two most distant localities not exceeding twelve rods and the ground nearly level:

Showing Depth of Root-Feeding as Indicated by the Water Content of the Soil August 24, 1889.

Depth of Sample.	Clover in Pasture.	Timothy and Blue Grass.	Corn.	Fallow Ground.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0–6 in.	8.39	6.55	6.97	16.28
6–12 in.	8.48	7.62	7.80	17.74
12–18 in.	12.42	11.49	11.60	19.88
18–24 in.	13.27	13.58	11.98	19.84
24–30 in.	13.52	13.26	10.84	18.56
40–43 in.	9.53	18.51	4.17	15.90
Distance of lower sample above water-table	2.36 ft.	1.97 ft.	2.12 ft.	2.22 ft.

This table shows clearly that root-feeding, in the case of both clover and corn, extended to a depth of at least four feet, and that the corn had fed deeper than the clover. It also shows that the timothy and blue grass had exhausted the soil moisture near the surface more than either of the other crops, but that the depth of feeding was less.

The strong difference which is shown to exist between the amount of water in the fallow ground and the ground bearing crops shows in a marked manner the strong drying influence of growing vegetation upon the soil.

162. Capacity of Soil to Store Water.— The rainfall of our state during the summer season is rarely enough to meet the demands of vegetation during the growing period, but the soil acts as a reservoir, retaining considerable quantities of that which falls at other times. All soils, however, have not the same storage capacities, and hence on fields receiving the same rainfall the water supply for crops may be very unequal.

Klenze makes the following general statements in regard to the water capacity of different soils:

1. The saturation capacity of a given kind of soil increases as the size of the smallest particles decreases.

2. The capillary capacity of a given soil containing only capillary spaces decreases as it is made more close and firm.

3. The saturation capacity of soils is decreased by increasing the number of cavities which are larger than the capillary spaces.

4. The saturation capacity of soil decreases as the temperature increases.

In the following table are given the percentage and absolute capillary capacity of a section of soil 5 feet deep, as found by experiment, the soil being in its natural condition:

	Per cent. of Water.	*Pounds of Water.*	*Inches of Water.*
Surface ft. of clay loam contained........	32.2	23.9	4.59
Second ft. of reddish clay contained......	23.8	22.2	4.26
Third ft. of reddish clay contained.........	24.5	22.7	4.37
Fourth ft. of clay and sand contained....	22.6	22.1	4.25
Fifth ft. of fine sand contained..........	17.5	19.6	3.77
Total		110.5	21.24

These figures show that the actual storage capacity of 5 feet of soil is really very large, in the case in question, aggregating

$$\frac{43560 \times 110.5}{2000} = 2406.69 \text{ tons per acre,}$$

and this, at the rate of 325 tons of water per ton of dry matter, is sufficient, were it all available, to give a yield of

$$\frac{2406.69}{325} = 7.405 \text{ tons of dry matter.}$$

Fig. 42 represents the proportions by volume, of soil, air and water in the above section.

163. Proportion of Soil-Water Available to Plants.— Not all the water which soils contain is available to plants, and considerable must remain unused if large yields are expected; we have also seen that soil fully saturated is not in a suitable condition to produce crops. Hellriegel concludes from observations of his own that soils give the best results when they contain from 50 to 60 per. cent. of their saturation amounts, but this, I think, should be understood as applying strictly only to the upper 12 to 24 inches of soil because, as the season advances and the roots develop downward, the water of the subsoil is drawn upon gradually as it is needed, and the per cent. of saturation is reduced to the proper amount.

Fig. 44.

Showing the relative volumes of water, air and soil in the upper five feet of cultivated ground.

During the season of 1890 Litch Dent and White Australian Flint corn grew side by side at the Experiment Farm in a light clay loam underlaid with sand, the soil containing at the time of planting 22.41 per cent. of water, and at the time of cutting 15.45 per cent., the mean saturation capacity being about 25 per cent. The Dent gave a yield of 9,875 pounds of dry matter per acre and the Flint 6,000 pounds. The amount of water lost by transpiration, evaporation and drainage was at the rate of 456 pounds of water per pound of dry matter for the Dent corn, and of 610 pounds for the Flint.

An examination of the figures in **160** will show how completely crops may reduce the water-content of soil during dry seasons; those given there, for corn, being from the same locality as the above for the year 1889.

164. Kinds of Soils which Yield Their Moisture to Plants Most Completely.— The sandy soils yield their moisture to plants much more completely than do the clayey and other soils having a greater water capacity. This is clearly shown in **160,** where sand, at the bottom under the corn, contains only 4.17 per cent. while the clay with sand mixed, in the second foot of the same section, contains an average of 11.79 per cent. The saturation capacity of the first is about 18 per cent., while that of the latter is about 26 per cent. The sand had given up more than three-fourths of its water while the clay still retained nearly one-half.

If we compare the absolute amounts of water given up by each of the two soils in question we shall find that the sand had yielded 13.83 pounds per cubic foot, while the clay had yielded only 12.5 pounds. It thus becomes evident that while the percentage capacity of the sand is much below that of clay its greater weight per cubic foot and the greater freedom with which it yields water to plants makes its practical storage capacity for water, so far as crops are concerned, nearly as great as the loamy clays. It is thus very clear that a sandy soil kept well fertilized has many advantages over the colder, less perfectly aerated and more obstinate clayey ones, which crack badly in excessively dry weather and become supersaturated in wet seasons.

165. Movements of Soil Water.— The water in the ground is subject to at least three classes of movements:

1. Those due to gravitation.
2. Those due to capillarity.
3. Those due to gaseous tension.

The direction of movement in each of these cases may be either:

1. Downward.
2. Lateral.
3. Upward.

The gravitational movements are the most rapid, most extended and belong to two types:

1. Percolation movements.
2. Drainage or current movements.

The percolation movements are, as a rule, slower than the drainage movements and are usually downward, being only occasionally and locally upward; they consist of the slow filtering of water through the smaller soil pores. It is chiefly by percolation that all water finds its way into the ground.

The drainage currents consist of those portions of the percolation waters which could not be retained in the surface soil by capillary action. They move like streams of water on the surface or like currents through pipes, giving rise to springs and flowing wells.

The capillary movements, **81** to **83**, constitute the slow creeping of water over the surface of soil particles and those of root-hairs. In direction they are chiefly toward the surface of the ground and toward the root-hairs, during the time when these are in action; but after showers there may be capillary movement downward provided there is unsaturated soil below, but even under these conditions it will not always occur.

The gaseous tension movements originate in the changes in volume of the confined air due to changes of temperature and of atmospheric pressure referred to in **101** and **158.**

166. Rate of Percolation.— The rate at which water percolates through soils varies with the character and physical condition of the soil. As a general rule the percolation is more rapid through the coarse-grained soils than it is through those of a finer texture, and it is on this account that sandy soils leach so badly. Clayey subsoils, especially if they are underlaid with sand, very often shrink and break into great numbers of small cuboidal blocks leaving numerous fissures between them which open down to the sand below; through these a large amount of percolation may take place; and this effect is greatly intensified when the surface of the ground becomes cracked, as it often does when not prevented by cultivation. When in this condition such soils may leach even worse than sandy soil. The perforations made by earthworms and other burrowing animals also exert a considerable effect upon the percolation of water and the leaching of soils.

In case a winter sets in with fall rains insufficient to saturate the soil and close up the shrinkage cracks and the channels formed by burrowing animals, considerable water finds its way into the ground after it has been deeply frozen. During the winter rains and thaws which occurred in 1889, 1890 and 1891, there was a large amount of percolation on the Experiment Farm made evident by the alternate starting and stopping of the discharge of water in the tile drains. These facts have a significance in their bearing upon the practice of winter hauling and spreading of manure.

167. Rate of Capillary Movement.— The rate of capillary movement in soils varies with the kind of soil, with the physical conditions, and also with the amount of water it contains. It appears to be more rapid in sand than it is in clay, and more rapid in clay containing humus than in that without. It is more rapid in a well firmed soil than in one possessing large pores. The degree of closeness may, however, be so great as to impede the rate of movement.

I have found that water may rise through 4 feet of fine quartz sand at a rate exceeding 1.75 pounds per square foot in 24 hours, and in a light clay loam at a rate greater than 1.27 pounds per square foot. In these cases, however, the soil was devoid of all spaces except those produced by the form and size of the particles, and the rate was measured by the amount of evaporation; but as the soil remained wet at the surface throughout the experiment the possible capillary rates must exceed those stated by undetermined amounts. I have found changes in the water-content of the soils of fields which indicate that, under these conditions, the rate of capillary movement, when the soil is wet, may exceed 1.66 pounds per square foot.

When the soil is perfectly dry the rate at which water moves through it is relatively very slow, so slow that five cylinders of soil, each 6 inches in diameter and 12 inches high, standing in water one inch deep, and in a saturated atmosphere, required the intervals stated below for water to reach the surface in sufficient quantity to make it appear wet.

In clay loam, time required to travel 11 inches....................	6 days.
In reddish clay, time required to travel 11 inches..................	22 days.
In reddish clay, time required to travel 11 inches..................	18 days.
In clay with sand, time required to travel 11 inches...............	6 days.
In very fine sand, time required to travel 11 inches...............	2 days.

These are very fundamental facts in their bearing on the control of evaporation by surface tillage.

168. Translocation of Soil-Water.— It frequently happens, in certain soils after rains and in most if not all soils after rolling or firming, that water is brought up into the surface stratum from the deeper layers; this change of position is named *translocation* and has important bearings upon questions of tillage.

The translocation caused by rolling or otherwise firming the soil is due to the fact that reducing the non-capillary pores in soil increases its capacity for water and the rate at which water will move into it by capillarity, and this influence is sometimes felt to a depth of three to four feet. The deeper soil-waters may in this way, therefore, be brought to the surface or within the zone of root growth.

The translocation caused by wetting the surface depends upon the principle that when the per cent. of water in a soil has fallen below a certain limit its ability to take water from another soil is decreased, and that when it has risen above a certain limit this ability is then diminished, that is, for each soil there is a certain water-content at which the water enters it at the most rapid rate. It therefore frequently happens that the water-content of the surface soil is below that at which water enters it most rapidly, and when a rain comes which restores its strongest action again, water is also taken into it from the soil below so that the surface stratum may, in consequence of a rain, receive more water than actually fell, while the soil below is, by translocation, rendered actually drier than before the rain. This fact has an important bearing upon surface tillage immediately after showers, upon the transplanting and watering of trees and upon questions of irrigation. If the surface, after a rain, is allowed to remain undisturbed, the rapid evaporation which occurs in such cases may take away in a short time not only that which had fallen but also that which was brought up by capillarity from below, whereas simply stirring the surface, destroying the capillary connection below, would allow the surface only to dry and act as a mulch, retaining the balance in the ground for the use of the crop.

169. Influence of Topography on Percolation. — The slope of the surface influences, sometimes in a marked manner, the percolation of rain-water and the water-content of the soil. Whenever rains occur which are sufficiently heavy to cause water to flow along the surface, from the hill-tops toward the lower and flatter areas, less water is left to percolate on the highest sloping ground, while the more nearly level areas may have not only the water which falls as rain upon them but a portion of that which has fallen upon other ground. Nor is this all; as the water-table is generally higher under the high ground, **157,** there is a constant tendency for the water in the soil itself to percolate from the high lands toward the low lands, and so, when the water-table here lies within reach of root action, to increase the water supply for the season, sometimes to a disadvantageous extent, making drainage necessary where in the absence of the high land it would not be needed.

In those cases where the water-table under the high land is below the level of the surface of the low lands, and the low lands remain long over-saturated, there is a tendency for the water to percolate toward the higher ground, but of course to return again at a later season.

170. Influence of Topography upon Evaporation. It is a matter of common observation that the south and southwest slopes of steep hills are often simply grass-covered, while the north and northeast slopes may be heavily wooded. This difference of verdure is due largely to a difference in soil moisture on the opposite slopes, which is determined chiefly by the difference in the rate of evaporation upon the two slopes.

Other things being the same, the rate of evaporation, in our latitude, is greatest on hill-sides sloping to the southwest and least on those sloping to the northeast. Several conditions work in conjunction to produce this effect:

1. More air comes in contact with windward than with leeward slopes, and as rapid changes of air over a moist surface increase the amount of water taken up, the evaporation is greater on the windward slope.

2. Our prevailing winds, during the growing season, are southwesterly, and hence more air comes in contact with southwest slopes.

3. Westerly and northerly winds are, with us, almost always drier than easterly and southerly winds, and as evaporation is more rapid under dry than under moist air the westerly slopes are drier than easterly ones.

4. Other things being the same, surfaces which are nearest vertical to the sun's rays receive most heat, and for this reason southward slopes, in the northern hemisphere, become most

heated, and as evaporation takes place more rapidly at high than at low temperatures, southerly and southwesterly slopes lose most moisture from this cause. Fig. 45 shows how a surface

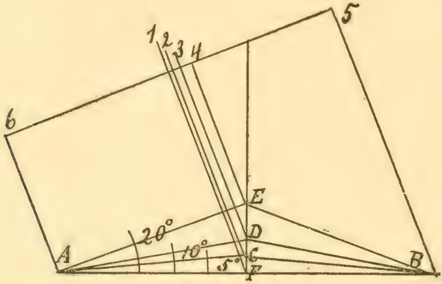


Fig. 45.

inclined toward the south must receive more heat per square foot than either the level surface or the one inclined northward. If A65B is a section of a cylinder of sunshine falling upon the hill AEB, it is evident that A64E, the portion falling on the south slope, is greater than E45B, the portion falling on the north slope. It will also be evident that the 20-degree slope receives more heat than does the 5-degree slope, and this more than the level surface.

The effect of the wind upon the evaporation from the soil is at its maximum at the summit of a hill, because at this place the wind velocity is greatest, no matter from what direction it may be blowing.

171. Effect of Woodlands on Evaporation.— A piece of woodland which lies to the southwest and west of a field exerts a considerable effect upon the humidity of the air which traverses that field, the tendency being to make the air more moist. Taking a specific illustration, the air on the leeward side of a second growth black-oak grove was found, on one occasion, to contain 3.3 per cent. more moisture than did that on the windward side at the same time; and again, when the wind was in the opposite direction, observations in the same localities showed 3.8 per cent. more moisture on the leeward side, the observations in the four cases being taken about 10 rods from the margin of the grove. There was observed at the same time a difference of air temperature of 1.5° F., the leeward air being this much cooler in the field 10 rods from the grove, the width of the grove being about 30 rods and the trees from 20 to 30 feet high.

TILLAGE.

172. The Objects of Tillage.— The chief objects of tillage may be briefly stated as follows:

1. To destroy undesired vegetation.
2. To place organic matter of various kinds beneath the surface where it will more readily ferment and decay and be brought within reach of root action.
3. To develop a loose, mellow and uniform texture in certain soils.
4. To control the water-content of soil.
5. To control the aeration of soil. **154** and **155.**
6. To control the temperature of soil.

173. The Destruction of Undesired Vegetation.— In securing this object of tillage we have two classes of vegetation to destroy, one, like the prairie grasses of a virgin soil or like the cultivated meadow grasses, which must be destroyed before there is root room for the desired crop, and the other which is designated by the general term of weeds.

Plants spread out two broad surfaces, one in the air to obtain carbon dioxide, oxygen and sunshine, and the other in the soil to obtain water, nitrates and other food constituents. It requires but little study to reveal the fact that plants usually spread out their leaf surfaces in such a manner that each leaf shall be forced as little as possible to breathe the air of another leaf, and that one shall shade another as little as possible. In a dense forest or thicket no fact stands out more prominently than the race each plant makes to outreach its neighbor and get into bright sunshine and free air. A study of root development shows that the same law is followed beneath the surface. There are times of scarcity of food, and each root and rootlet tends to develop away from its neighbor into an unoccupied territory. Such facts teach, with abundant evidence, that there is no room for weeds in any soil where another crop is expected.

When we remember that each pound of dry matter requires more than 300 pounds of water taken from the soil, and that in most soils there is usually a scant supply of moisture at best, the importance of a weedless surface should be appreciated.

The following definite case will serve to show how rapidly weeds may consume the water of soil.

On May 13, 1889, the water-content in the soil, on adjoining margins of a field just planted to corn and one of clover and timothy, was determined on the Experiment Farm, with the results below:

	Corn ground.	Clover ground.
	Per cent. of water.	*Per cent. of water.*
Surface to 6 in. contained........	23.33	9.59
12 to 18 in. contained............	19.13	14.79
18 to 24 in. contained............	16.85	13.75

These figures illustrate in a very forcible manner the great power vegetation has of withdrawing water from the soil, how naked tillage conserves it, and the importance, in all except the wettest seasons, of not allowing weeds to occupy cultivated fields.

174. Plowing in Organic Matter.— The decomposition of most animal and vegetable tissues is the result of a growth in and upon them of micro-organisms which, like all other living things, require a bountiful supply of moisture. Moisture is usually found in abundance at the surface in the shade of dense forests, but in open cultivated fields the stems of plants and coarse manures are too dry, most of the time, to maintain the life of micro-organisms unless they are buried a little distance below the surface where the rate of evaporation will be checked and where there is a better capillary connection between them and the water of the soil. In this condition, if the soil is sufficiently aerated so that the respiration of the life going on there is ample, the organic tissues are rapidly broken down and quickly become available as food for crops.

175. Circumstances which Modify the Time and Depth of Plowing in of Manure.— We are yet a long way from being in possession of the rigid knowledge which is needed to make specific and exact statements regarding matters like these. There are some general statements, however, which may be helpful in practice if not followed too implicitly and without judgment.

Coarse manures, when plowed in, tend at first, to cut off the capillary connection with the soil-water below, and where the plowing occurs in the spring, certain crops are liable to suffer from drought because of a lack of moisture in the surface soil; this is especially liable to be the case if the spring is dry. If heavy, soaking rains follow the plowing in of such manure, the soil particles are washed in between the straws and other litter and a good connection established between the surface and the soil below. This is what does happen usually in the case of fall plowing, and explains why on many, if not most, soils, the fall plowing in of such manures is preferable. It is evident that on soils naturally too wet, and especially in wet seasons, the spring plowing, in such cases, might be preferable.

If manure is plowed in too deeply, and especially if the soil is close and fine, there is danger of too little air to permit of rapid decay, and the effects of manure under such conditions will be only partially felt the first season.

If the soil is a leachy one, plowing the manure in deeply tends to increase the loss by underdrainage.

176. Effect of Manures on the Water Capacity of Soils.— Humus stands foremost among the ingredients of soil in its power to retain capillary water. The barnyard manures, besides containing large quantities of saline fertilizers, contain much undigested vegetable fiber, which, when plowed into the soil, tends to decay into ordinary soil humus and thus to increase the water capacity of the lands to which they are applied; in this respect they have a superior value, when compared with most commercial fertilizers, especially if it shall be established that organic matter, in contact with dry earth, does oxidize with a loss of free nitrogen.

177. The Importance of Good Tilth.— It is a generally recognized fact that one of the chief objects of tillage is to produce a mellow seed-bed of uniform texture, and there are several desirable ends which are met, wholly or in part, by good tilth.

One of the strong recommendations of a rich sandy soil is found in the evenness of its texture and the lack of adhesion between its grains which permit of almost perfect symmetry in the development of roots and allows the root hairs to occupy most completely the soil interspaces. When this is true, not only is all the soil laid under tribute, but each and every rootlet, with its numerous root hairs, is doing full duty. If, on the other hand, the soil is uneven and filled with hard lumps, a large portion of it is not only unavailable but it stands as a positive hindrance to root development, checking rapid root-growth and making a much greater actual length of roots necessary in order to come in contact with a sufficient amount of soil. Nor is this all; during the process of cultivation the lumps tend to work to the surface and become very dry; in this condition they absorb a large percentage of the summer rains, and, as they are almost completely surrounded by free air, they give back this moisture to the atmosphere and thus prevent it from rendering any service.

On the principle of oxidation of nitrogenous compounds with the liberation of free nitrogen the lumpy condition of soil should be expected to be a large source of loss of that important element of plant food.

Mellow soil favors root-development in being easily crowded aside by the expanding roots, and this is a matter of some importance in all the succulent root crops, like beets, parsnips, turnips and carrots, for the actual soil displacement in an acre of these crops is very great, and the conclusion seems irresistible that a hard soil must mechanically impede root-growth in such crops to a large extent.

A mellow, even-textured soil is likely to be much better aerated than one not in this condition and better supplied with moisture also.

178. Control of the Water-Content of Soils.— The operations of tillage aiming to control the water-content of soils proceed along one of three lines of action:

1. To conserve the water contained in the soil.
   - (a) By surface tillage.
   - (b) By flat culture.
   - (c) By mulching.

2. To reduce the quantity of water in the soil.
   (a) By deep tillage.
   (b) By decreasing the water capacity.
   (c) By ridge culture.
   (d) By surface drainage.
   (e) By underdrainage.
   (f) By tree planting.
3. To increase the quantity of water in the soil.
   (a) By increasing the water capacity.
   (b) By irrigation.
   (c) By firming the surface soil.

179. Conservation of Soil Water.— On the great majority of cultivated lands there is, as a rule, an insufficient supply of moisture to give the largest possible yield when other things are favorable, and hence it becomes a matter of importance to check the evaporation from the soil surface and divert the water currents through the growing crop.

180. Surface Tillage to Check Evaporation.— In one of my experiments, where the rate of evaporation from the undisturbed surface of clay loam had been going on at the rate of .9 pounds per square foot in 24 hours, simply removing the crust of salts brought to the surface and deposited there by evaporation, increased the rate of evaporation to 1.27 pounds per square foot in the same time, and I found the same fact true for fine sand. These facts have a bearing upon the practice of harrowing winter grain in the spring, suggesting that the practice may, in some cases, cause a waste of water.

In the case of the fine sand referred to, the evaporation had been taking place at the rate of .91 pounds per square foot in 24 hours, just before the crust was removed; after its removal the surface was cut in small squares with the blade of a sharp knife held vertical to the surface, and then the rate of evaporation rose from .91 pounds to 1.75 pounds per square foot per day. On removing a thin layer of the sand, and replacing it immediately, the rate of evaporation fell to less than .5 pounds per square foot daily. It is thus shown that one form of surface tillage may increase the rate of evaporation while another form may check it in a very decided manner.

A tool working like the disc harrow when the discs are running at a small angle, simply slicing the surface as the knife did, increases the surface exposed to the air without destroying the capillary connection with the soil below, and tends to hasten rather than retard evaporation; but if the tool completely removes a surface layer, leaving the ground covered with a layer of loose soil, a mulch is provided which excludes the air, in a measure, and greatly retards evaporation.

181. Flat Cultivation.— When the surface of the ground is thrown into ridges, as in hilling potatoes or corn, the amount of surface exposed to the air is increased, and this, other things being the same, tends to increase the rate of evaporation from the surface and diminish the supply of moisture for the crop. When three-foot rows are ridged to a hight of six inches the surface is increased more than 5 per cent., and when ridged to the hight of eight inches more than 9 per cent.

182. Deep Tillage to Increase Evaporation.— When the ground is stirred to a considerable depth repeatedly there is a large and rapid evaporation from the soil stirred, and this is one of the chief objects of discing and harrowing lands that are to be planted early in the spring. The ground is cold from the low temperature of winter and from the large volume of contained water which requires a great amount of heat to warm it. Getting rid of this moisture by deep tillage provides a warm and mellow seed-bed, well aerated, which also acts as a mulch to conserve the deeper water of the soil until a time when it is needed.

183. Firming the Ground to Control Moisture.— Rolling or otherwise firming land, after it has been tilled, may have two distinct objects as regards the control of soil water. These are:

1. To dry the soil as a whole.
2. To increase the moisture of the seed-bed.

We have shown by two distinct lines of investigation conducted in the fields of the Experiment Farm that rolling tilled land tends to dry the soil, as a whole, the effect being measurable at a depth of at least four feet. This drying effect is brought about —

1. By increasing the capillary power of the surface.
2. By increasing the surface temperature.
3. By increasing the wind velocity at the surface.

These three important effects tending to dry the soil may be employed to secure the most rapid evaporation when repeated deep tillage and rolling follow each other at short intervals. Stirring the soil deeply, exposes a large surface of moist earth to the air which dries quickly, and if this is rolled as soon as dry enough, the soil again becomes wet at the expense of the deeper soil moisture, and this is soon lost if deep tillage follows. Repetitions of these processes are an excellent treatment for a seed-bed in too damp cold soil.

When the soil of the seed-bed is too dry for the proper germination of seeds, then firming the ground tends to increase the moisture by bringing it from below to the place where it is most needed, and the press-wheels used on various forms of drills and planters have this to recommend them. They concentrate the moisture at the points where it is most needed, leaving the remaining portion of the field covered with a loose protecting mulch. In the case of broadcast seeding, rolling is generally required, if the seed-bed is too dry, and if this rolling is followed, in one or two days, with a light harrow to develop a thin mulch, it will check the surface evaporation without destroying the good capillary connections produced by the rolling.

184. Puddled Soils.— All soils when completely or nearly saturated with moisture become very plastic, and when they are worked under these conditions the water and air are crowded out of the larger interspaces and the soil becomes much more compact. This is especially true of the adhesive clayey soils whose particles, after such treatment, become so firmly united as to develop into obstinate clods so injurious to good tilth. Great care should always be taken not to work soils when they are too wet. The roller should never be used when the soil will adhere to its surface.

185. Advantages of a Warm Soil.— The advantages of a warm soil are several, and may be briefly stated as follows:

1. Soil ingredients are more soluble in warm than in cold water.

2. Root absorption is more rapid at warm than at cold temperatures.

3. Germination is more rapid at moderately high than at low temperatures.

4. Nitrification takes place most rapidly at about 90° F.

It is a general law with all living beings that their vital processes can go on normally only within certain limits of temperature, and the range is usually a comparatively narrow one. In our own case a change of a few degrees above or below 98° F. in the body, as a whole, produces very serious disturbances; and while these ranges are larger with plants, yet they are not so wide but that the bounds may frequently be crossed.

186. Best Soil Temperature in Certain Cases.— Haberlandt found that the germination of wheat, rye, oats and flax is best at 77° to 87.8° F., and that corn and pumpkins germinate best between 92° and 101° F. He found, for example, that when corn germinated in three days at a soil temperature of 65.3° F., it required 11 days to germinate at 51° F., and while oats germinated in two days at a temperature of 65.3° F., 7 days were required when the temperature was 41° F.

Sachs found that tobacco and pumpkin plants wilted when the soil temperature fell much below 55° F. on account of a too slow root absorption. It is found that the "mother of petre" develops niter at an appreciable rate only above a temperature of 54° F., that its maximum power is manifested at 98° F., and that at 113° F. its power is less strong than at 59° F.

187. Control of Soil Temperature.— The temperature of soils may be increased in several ways as follows:

1. By diminishing the water capacity.
2. By diminishing the water content.
3. By diminishing the surface evaporation. **127.**
4. By smoothing the surface.
5. By means of fermenting manures.
6. By increasing percolation.

It has been shown, **124** and **127,** that diminishing the water in soil and lessening the surface evaporation favors, in a marked degree, the production of high soil temperatures, while the reverse conditions tend in the opposite direction.

Smoothing the surface, as in the case of rolling, has a very appreciable effect in raising the soil temperature. The results observed in a special case are given in Fig. 46. It will be observed that the air temperature over the unrolled ground is higher than it is over the rolled, which shows that this soil must be losing heat faster; and since both surfaces must have been receiving the same amounts from the sun, it is plain that if the air is warmed more over the unrolled ground the soil itself must be warmed less.

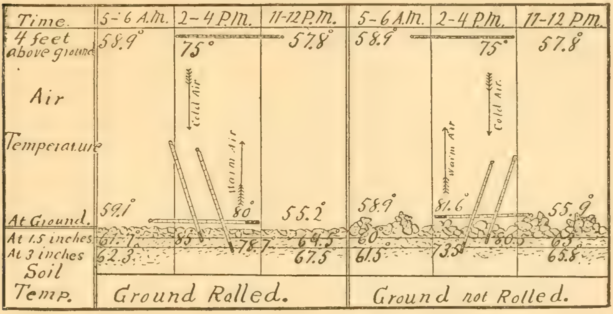


Fig. 46.

Showing differences of temperature of rolled and unrolled soil and associated air temperatures.

The air receives more heat from the unrolled ground for two reasons.

1. Its many lumps present a much greater contact surface.
2. The lumps being dry become warmer at the surface than the more moist rolled soil.

Further than this, the lumps, being in poor connection with the soil below, conduct their heat slowly downward while at the same time they shade the lower soil; and by exposing a very large surface to the sky they cool rapidly by radiation.

The measured differences of soil temperature due to this cause have been as great as 6.5° to 10° F., the lower figure having been observed at a depth of three inches and the higher at 1.5 inches.

The heating effect of fermenting manures in the soil has been observed to produce a rise in temperature of nearly 1° F.

In the case of well drained soil the percolation of warm summer rains often carries rapidly and deeply into the soil considerable heat and thus raises the temperature directly, and as this water must evaporate more slowly from the drained soil, if at all, than from the undrained, it is not cooled as much as it might have been had percolation not occurred, thus leaving all the water to evaporate in a short time.

IMPLEMENTS OF TILLAGE.

188. The Plow.— Foremost among the implements of tillage unquestionably must be placed the plow. Historically, it is probably one of the oldest of farm tools, and when viewed from the standpoint of evolution no instrument has advanced more slowly or has been changed more profoundly. It has grown from a natural fork formed by the branches of a tree, as depicted on an ancient monument in Asia Minor, with the shorter limb simply sharpened and laboriously guided and awkwardly drawn through the soil by the longer arm, to our present almost self-guiding twisted wedge of hardened steel susceptible of an extreme polish.

189. The Work Done by a Plow.— The mechanical principles which do or should dictate the construction of a plow can be most easily comprehended when a clear notion of the work a plow is expected to perform is first in mind. Speaking simply of the sod and stubble plows, the first has two functions:

1. A cutting function.
2. An inverting function.

The stubble plow has three functions:

1. A cutting function.
2. A pulverizing function.
3. An inverting function.

With both plows the cutting is required in two planes, one vertical and the other horizontal, to separate a furrow-slice of the desired width and depth. The inversion of the furrow-slice, required in both cases, necessitates first a lifting of the slice and then a rolling of it to one side, bottom up. The pulverizing of the furrow-slice is most simply done by bending the slice upon itself more or less abruptly and then dropping it suddenly upon the ground.

190. The Mechanical Principles of Plows.— The plows under consideration are sliding three-sided wedges having one horizontal plane face, called the *sole;* one vertical plane face, called the *land-side*, and a third twisted and oblique face, one portion of which is called the *share* and the other the *mold-board.* The two lines formed by the meeting of the twisted oblique face with the land-side and with the sole are cutting edges. This wedge is simply shoved through the ground by a force applied to the standard through the plow-beam, and is guided in its course by a pair of levers in the form of handles.

A study of Figs. 47 to 52 will show that, in these types of plows, the cutting edges are very oblique to the directions in which they move, and that the obliquity is greatest in the *breaking* type. It will also be seen that the strong difference between the elevating and inverting surfaces or mold-boards, in these plows, consists in the steepness of the inclined surface and the abruptness of the twist in them, these being least abrupt in the breaking plow, Fig. 52, and most abrupt in the full stubble, Fig. 47.

191. Advantage of Oblique Cutting Edges.— There are several conditions which have led to placing the cutting edges of plows oblique to the direction in which they are drawn.

1. The shin, coulter and share free themselves from roots, stubble and grass more perfectly.

2. The shin, coulter and share require less power to cut roots.

3. The plow enters the ground more easily and runs more steadily.

4. There is less friction of the furrow slice on the inverting surface.

When the coulter is placed with its cutting edge in a nearly vertical attitude straw and roots tend to double around the edge and clog under the beam, increasing the draft and tending to draw the plow out of the ground. If the coulter is dull and the roots are long and tough, they fold over the edge and thus increase the draft by making the edge in the soil thicker. When the cutting edge is made to incline backward the roots tend to slide upward and are severed by a partially *drawing* cut, and this requires a less intense power than the straight chisel thrust.

The obliquity of the share, particularly in the sod plow where a large part of its work consists in cutting roots, materially lessens the draught by bringing a drawing cut upon the roots by forcing them sidewise in its wedging action and

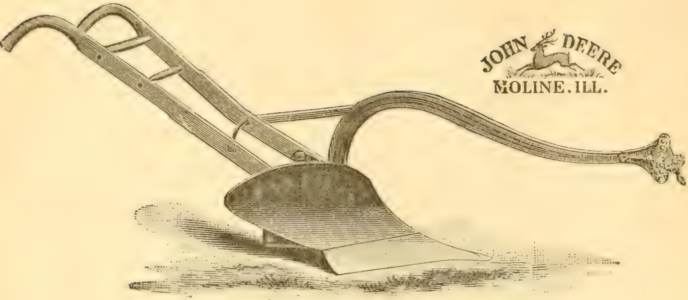


Fig. 47.

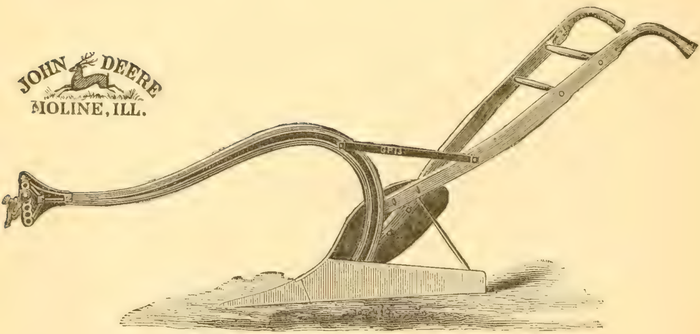


Fig. 48.

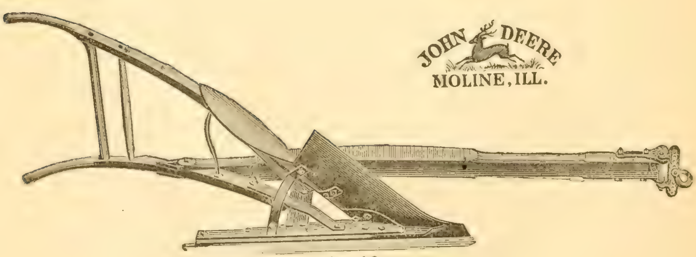


Fig. 49.

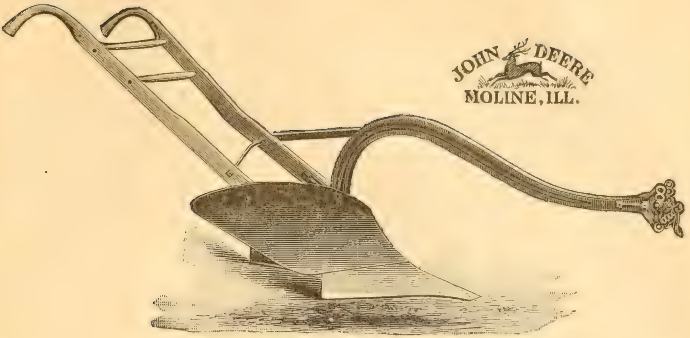


Fig. 50.

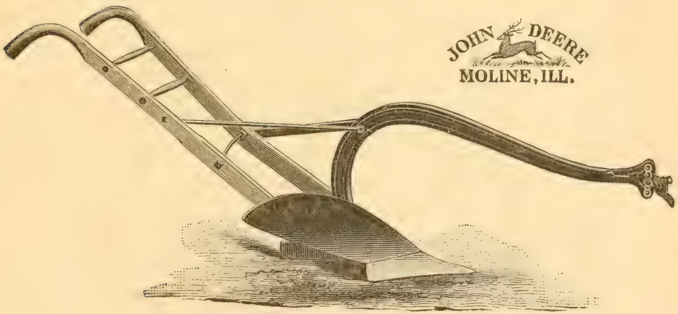


Fig. 51.

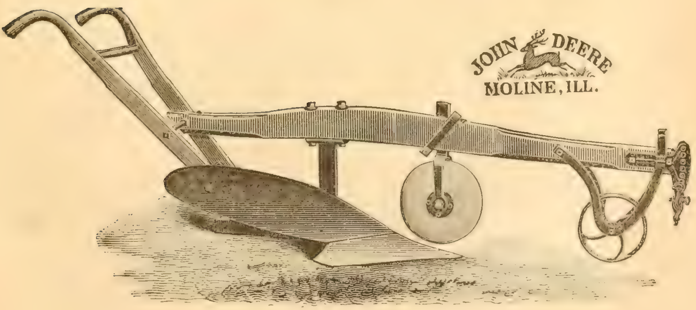


Fig. 52.

drawing the cutting edge across them while they are under tension.

When hard spots in the furrow-slice are to be cut through the more oblique the share is the greater distance will the horses travel before it is cut off, and as the resistance is overcome in a longer time less power is required per second. Of course so much work must be done in plowing a given length of furrow, but the oblique share tends to develop an even, steady pull all the time, while the less oblique form allows the inequalities of the soil to develop an irregular draft which is more wasteful. It is, in effect, like the triangular sections in a mowing machine, which allow the horses to be cutting all the time.

192. Function of the Land-side.— The land-side is made necessary by the inequalities of the soil and the tendency of the horses to vary their course from a straight line. When the oblique share is brought against a more resisting spot of soil, a root or a small pebble, were it not for the land-side the plow would run too far to land and the furrow would become crooked. This side pressure developed by the share produces friction between the land-side and the edge of the furrow and the land-side should, therefore, be of such a character as to move most easily under this friction.

193. The Line of Draft.— There is a certain point, A, Fig. 53, in the mold-board of the plow, to which if the horses could be attached the plow would "swim free" in the soil; and the attachment of the team to the bridle, B, of the plow should be in such a position that the point of attachment, D,

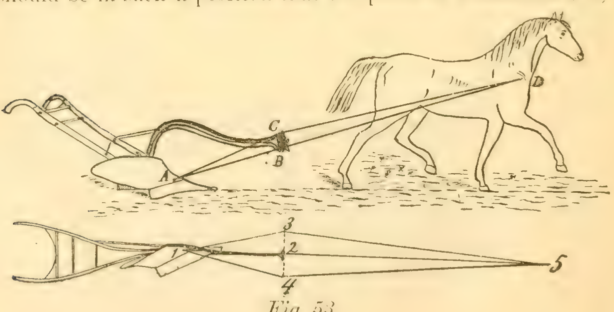


Fig. 53.

of the traces to the harness, shall lie in the same plane with A, as represented by the line ABD. If the attachment to the bridle is made at C the draft of the team will draw the plow more deeply into the ground; and should it be at some point below B, or, what would amount to the same thing, should the horses be hitched shorter, the draft would tend to run the plow out of the ground. Not only is it important to adjust the plow so that it will "swim free" vertically, but it should likewise be adjusted to "swim free" from right to left. When this is done, a properly constructed plow will almost hold itself and will then move with the least possible draft.

If the plow requires any considerable power to be applied to the handles in guiding it, no matter in what direction, not only is the work harder for the man, but the draft is harder on the team and at the same time the plow is wearing out more rapidly. So, too, the man who carelessly holds his plow, allowing it to waver from side to side and run shallow and deep, is making not only more work for himself and for his team, but is unnecessarily wearing out his plow and at the same time producing a seed-bed which will necessarily yield a smaller crop.

194. Draft of the Plow.— The records we have, thus far, bearing upon the draft of plows are, in many respects, very unsatisfactory, owing partly to inherent difficulties in making measurements which represent the actual resistance of the soil to the plow, partially because of unreliable methods of measurements, and again because the varying percentage of water in soil greatly modifies its plasticity and its weight.

Mr. Pusey, in 1840, in England, made some extended trials of the draft of plows in soils of different kinds, and the figures below show the average results of trials with ten plows, the total mean draft being given and also the draft in pounds per square inch of a cross-section of the furrows plowed:

	No. of Plows.	*Size of furrow.*	*Draft.*	*Draft per sq. in.*
Loamy sand	10	5x9	227 lbs.	5.04 lbs.
Sandy loam	10	5x9	250 "	5.55 "
Moor soil	10	5x9	280 "	6.22 "
Strong loam	10	5x9	440 "	9.78 "
Blue clay	10	5x9	661 "	14.69 "
Sandy loam (J. C. Morton)	5	6x9	566 "	10.48 "
Stiff clay loam (N. Y. 1850)	14	7x10	407 "	5.81 "

Prof. J. W. Sanborn has made extended trials of plows recently in Missouri and Utah. The average of all his trials, reported in Bulletin No. 2 of Utah Experiment Station, is 5.98 pounds per square inch of furrow turned. If we separate these trials historically we get, by leaving the clay out of the English trials:

English trials, 1840, draft per sq. in. 7.41 lbs.
American trials, 1850, draft per sq. in. 5.81 lbs.
American trials, 1890, draft per sq. in. 5.98 lbs.

Both English and American experiments agree in showing a decrease of power per square inch with increase of width of furrow when the depth remains the same; but this statement should not be construed as saying that a wide furrow can be plowed with less total draft than a narrow one.

The effect of depth on the draft is not so clearly shown by the experiments on record, but they appear to indicate an increase of power, per square inch, required with increase of depth.

195. Effect of the Beam-wheel on the Draft of the Plow.— If the wheel under the beam of the plow is so adjusted in hight as not to bring the attachment of the horses to the plow-bridle above the line of draft there is found a material lessening of the draft of the plow with its use. The reduction of the draft is occasioned by the more even running of the plow, making it unnecessary for the plowman to be alternately pressing down upon the handles, or raising them, in order to maintain the desired depth of furrow. If the wheel is so high as to bring the line of draft in the condition represented by the line ABD, Fig. 53, a part of the power of the team is expended in producing pressure downward upon the wheel while the full resistance of the plow still remains to be overcome. The proper adjustment of this wheel is secured when it simply rolls on even ground without carrying weight; when in this condition it will prevent the plow from entering too deeply into the less resisting soils, and will act to force it deeper into the harder portions.

196. Draft of Sulky Plows.— It is generally claimed by plow manufacturers that sulky plows are of lighter draft, relatively, than the free-swinging types, the claim being based upon the assumption that the friction of the sole and land-side are transferred to the well oiled axles of the wheels and a rolling resistance secured instead of a sliding one, which ordinarily, on bare ground, is much less. The few records of trials, we have seen, do not appear to show a material differ-

Fig. 54.

ence in the draft. There seems to be no good reason, however, why a sulky plow, *when properly hung* and with the line of draft so adjusted that the power of the horses is not converted into a downward pressure upon the wheels, should not lessen the draft, and especially in the gang types. If a plow of the requisite strength could be made so light that the up-

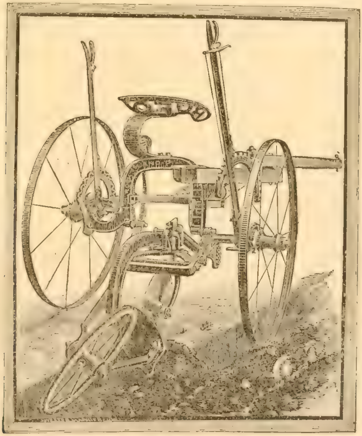


Fig. 55.

ward draft against the furrow-slice were sufficient to take the weight entirely from the ground, and if the adjustment for landing were perfect, there would remain only the friction of the furrow-slice itself. In such a case the only work left for wheels would be such as has been described for the beam-wheel of the walking plow, but such a condition appears practically impossible.

197. Effect of Coulters on the Draft of Plows.— The use of the coulter is chiefly confined to sod plowing, and in this work it is simply indispensable in securing a proper furrow-slice where there is any considerable turf. The early English trials, and those of Gould, in New York, indicate a saving of power by their use, but Professor Sanborn, through his Missouri and Utah experiments, comes to the conclusion that they increase the draft from 10 to 15 per cent. and advises farmers to dispense with them. This position is surprising, in the face of general practice, and I believe untenable. When the coulter is very thick, dull and set in an improper place or attitude it will necessarily increase the draft.

If the coulter is thick and set ahead of the lifting action of the plow-point, and especially if it is dull, it offers a large resistance by being forced to compress the soil and cut the roots at the greatest disadvantage; but if it is so placed, in the rear of the point, as to do its cutting and side-wedging above the place where the point and share are lifting and cutting, the two wedging and cutting bodies mutually assist each other; the roots in both cases are then severed while under strain and to a greater extent, with a drawing cut and, I believe, with an appreciable saving of power. So, too, when the wheel coulter is dull and set far forward, it becomes necessary to hitch to the plow-bridle at so high a point, in order to force the coulter into the ground, that there may be loss of power as there may be with a beam-wheel; but when this form of coulter is sharp and set well back where the beam of the plow acts with leverage to force the coulter through the sod and where the cutting occurs under the lifting strain of the point and mold-board, there can but be a lessening of draft in tough sod.

198. The Scouring of Plows.— There are certain soils whose texture and composition are such that the most perfect plow surfaces fail to shed them completely. The particles of most such soils are extremely minute, **153**, and often contain much silica. In Fig. 51 is represented a type of one of the most successful plows for this class of soils. In form it resembles the breaking-plow, and the surface of the mold-board is very hard and susceptible of a high polish. The hard surface in these plows appears to be demanded to prevent it from becoming roughened by the scratching of hard soil particles; the less abrupt curvature of the mold-board diminishes the surface pressure and thus the liability to scratching, while the fine polish furnishes the fewest and shallowest depressions into which the extremely minute particles can be wedged by the pressure. It is a matter of great moment, in the care of such plows, that they be kept from rusting, because this quickly destroys the necessary polish.

199. Pulverizing Function of Plows.— The stubble plows are constructed so as to pulverize the soil at the time it is being overturned. This action of the plow can best be appreciated by taking a thick bunch of paper, like the leaves of a book, and bending it abruptly upon itself; when this is done it will be observed that the leaves slide upon one another, and through a greater distance the more abruptly the bending takes place. The steep mold-board of the full-stubble plow shown in Fig. 47 has this shearing action upon the soil as one of its chief functions and this necessarily increases its draft.

In selecting plows for the naturally mellow soils where pulverizing is unessential, the type represented in Fig. 50 should be taken, as, other conditions being the same, its draft will be lighter.

200. Driving Three Horses Abreast.— Much time and expense can be saved in plowing by driving three horses abreast, using a larger plow or a gang of plows, and this method is especially to be commended on all clear land where there is any considerable acreage to be plowed. In Fig. 56 is

Fig. 56.

represented a very compact type of three-horse evener, handled by the S. L. Sheldon Co., and Fig. 57 illustrates an approved method of driving three horses abreast.

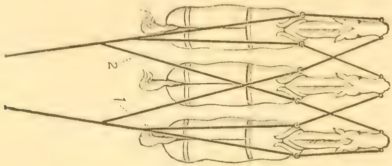


Fig. 57.

201. Care of Plows.—Next in importance to having good tools to work with is the keeping of them in proper working trim. It is extremely wasteful to purchase good tools and convert them into poor ones by lack of care, and in no case do these remarks apply with greater force than to plows. The John Deere Co., in their catalogues, make some remarks regarding the care of plow-shares, and through their kindness I am permitted to use some of their illustrations. Figs. 58 and 59 represent a proper and an improper form of point. A

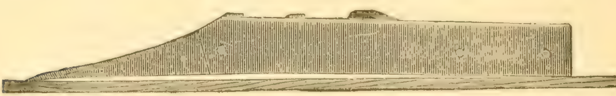


Fig. 58.

dull point may increase the draft of a plow six to eight per cent. and more, besides necessitating poorer work. The tendency of wear on the point is to change it from the sharp, slightly dipping form represented in Fig. 58 to the blunt upturned form shown in Fig. 59.

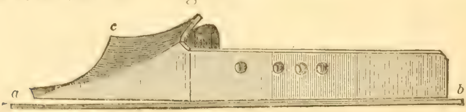


Fig. 59.

The heel of the share, like the point, is especially subject to wear, and soon comes into an improper shape. In case the ground is hard and dry, as is often the case during fall plowing, the share-heel requires a set shown in Fig. 60, dipping decidedly downward, preventing it from lifting out of the ground and tipping the plow to land. On the other hand, when the soil is mellow and damp, the heel of the share should be given a more nearly horizontal attitude, as shown in Fig. 61, to prevent it from sucking too deeply into the ground, and necessi-

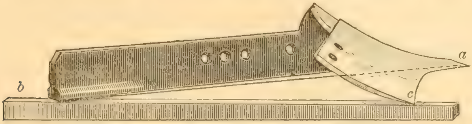


Fig. 60.

tating a steady pressure at the handles toward the land. It should be remembered that, whenever the plow requires a steady pressure at the handles in any direction in guiding it, there is a defect somewhere that should be remedied; because a pressure of only a few pounds on the long handles, working as levers, is transformed into friction, increasing the draft on the team and the wear on the plow.

In taking the share to the shop for setting or sharpening, the land-side should accompany it, so the blacksmith may have a guide in giving the proper set to it.

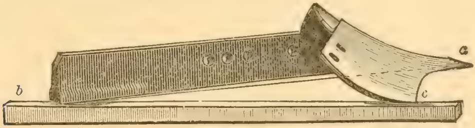


Fig. 61.

202. The Subsoil Plow.—One type of this instrument is represented in Fig. 62. Its function is nominally to loosen the ground to a greater depth than is practicable with the ordinary plow, thus securing deeper tillage without burying the humus-bearing soil too deeply below the surface. Its use requires great discretion, otherwise more harm than good may result from it. Better aeration, better drainage, deeper development of roots and less suffering from drought are advantages claimed for its use. For large yields of root crops a deep loose soil is indispensable, and one necessity for this is found in the fact that the thick roots require so much space which can only be secured by forcing the soil aside. There is great danger of puddling the soil in the use of the subsoil plow, because the surface may appear dry enough to work when the subsoil is too wet.

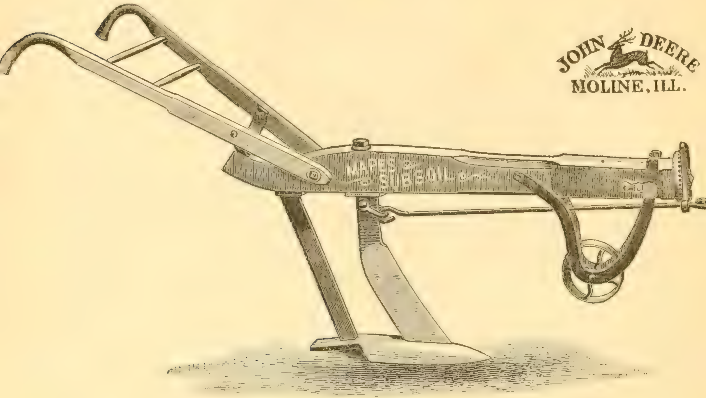


Fig. 62.

203. The Harrow.— As implements of tillage, harrows are used to secure several quite distinct ends:

1. To produce a shallow seed-bed.
2. To dry the soil preparatory to seeding.
3. To render the surface of the ground more even.
4. To pulverize the soil and secure a more even texture.
5. To cover seed.
6. To destroy young weeds.
7. To work manure into the surface soil.
8. To aerate the soil.
9. To check evaporation by developing a soil mulch.

According as one or another of these ends is to be secured, the character of the harrow should be different. In Figs. 63, 64 and 65 are represented three of the strongly marked types of harrows.

204. The Disc Harrow.— This harrow, Fig. 63, is distinctly a seed-bed-preparing and soil-drying tool and, in its adjustable types, may be made to work to a remarkable depth in fall plowing and in corn ground in the spring. An immense amount of work can be done with it where there is the necessary power to move it, which, although large when running deep, is really small when compared with the amount of soil

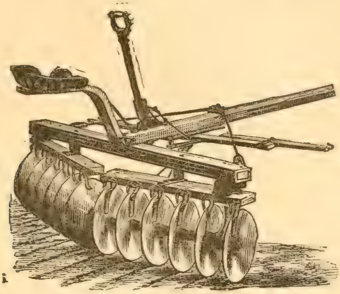


Fig. 63.

moved. Its rolling, concave, thin discs, when set obliquely, enable it to enter the soil and overturn it with less compression and relatively less friction than almost any other tool. As a first tool to loosen the soil and dry it rapidly it does excellent work. It is also very effective in pulverizing sod and may be used to advantage in covering sowed peas. This is also an excellent tool to work in a surface dressing of manure.

205. The Acme Harrow.—This tool, so far as its effects upon the soil are concerned, is like the disc harrow, but while it slices the soil and turns it over it does so with more compression, more friction and less movement. Like the disc har-

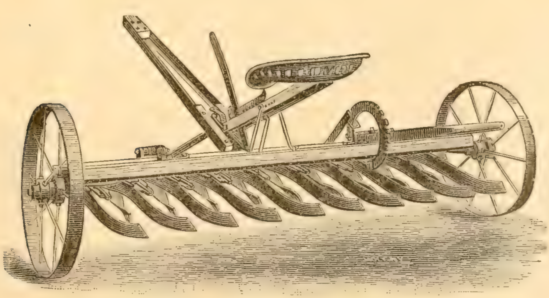


Fig. 64.

row it can be used to cut sod but has a greater tendency to drag them out of place.

206. The Tooth Harrows.— These tools, in their great variety of forms, are best adapted to secure the ends 3 to 9 named in **203**. The heavier types are, however, fair drying tools, especially on the more mellow soils, and in such situations, too, they give a sufficiently deep seed-bed for most of the small grains. To kill weeds, when just emerging from the ground, in potato and corn fields, and in developing a light

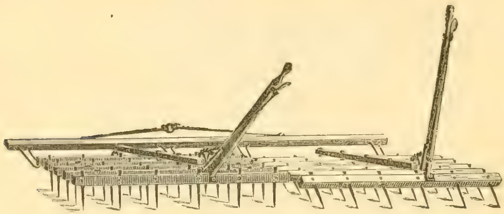


Fig. 65.

mulch to retard evaporation from the soil, there is no tool more effective or rapid in its execution than the light, many-toothed harrows.

207. Cultivators.— We have much to learn yet in regard to the real objects to be secured by summer tillage or cuilt-vation. Three chief objects appear to control present practice; they are:

1. To kill weeds.
2. To lessen surface evaporation.
3. To cover the roots of plants more deeply.

I believe we shall find, however, that one of the most important functions is

4. To secure better soil aeration.

When we remember that good aeration, plenty of moisture, and a warm temperature are among the essentials both to soil nitrification and root-growth, and that nature's ways of soil aeration are decidedly interfered with by our methods of tillage, it seems but natural that some equivalent should be supplied by our manner of working soil.

If soil aeration is conducive to its fertility it would appear to be rational practice with corn, potatoes and similar crops to adopt deep tillage during the early portion of the season before the roots have come to occupy the soil, to facilitate nitrification, and then to adopt purely surface tillage, to check evaporation and kill weeds, after the roots are well developed.

208. The Roller.—The firming of land with the roller, if used on the soil in the proper condition, has several beneficial effects:

1. It makes the soil warmer, **187.**
2. It increases the capacity of the surface soil for water and its capillary power, **183.**
3. In cases of broadcast seeding, the germination of seeds is more rapid and more complete on rolled than on unrolled ground.
4. It is maintained by many that larger yields are secured from rolling land.

In cases where the soil is too damp and cold the alternate use of the harrow and the roller will hasten its drying very much. Many farmers advocate the use of the roller on lands sowed to small grains after the grain is up, especially if a drought is threatened, the advantage claimed being the formation of a mulch by crushing the surface inequalities. It is one of those practices, however, which demands careful study and experiment to ascertain to what the advantage, if any, is due.

ELEMENTARY LESSONS

IN THE

PHYSICS OF AGRICULTURE.

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