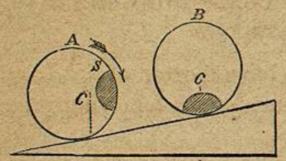
172. Paradoxes.—The tendency of the centre of gravity to reach its lowest possible point sometimes produces wonderful effects, or Paradoxes, for which the unlearned are at a loss to account. Thus, we know that a ball will roll down a sloping surface; but a ball of light wood may be made to roll up a sloping surface by inserting a piece of lead in one side.

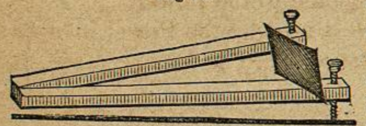
Fig. 78.



The ball A, for instance, loaded on one side with a plug of lead S, is placed on a sloping surface. The centre of gravity C, which is near S, at once tends to reach its lowest point; and owing to this tendency the ball rolls, till it reaches the position shown in B.

173. In like manner, a double cone, or body having the form of two sugar-loaves joined at their large ends, may be made to roll up an inclined plane. Fig. 79 represents two rails, joined at one end, but apart and somewhat elevated at the other. Place the double cone at the middle of the rails just described, and instead of rolling down to the narrow end it will roll up to the wide end. This is because the centre of gravity, though apparently going up, is really going down; for, as the rails diverge, they let the double cone further down between them.

Fig. 79.



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sphere or oval body be increased? For what are bases of this shape used? What stones are of this shape? 172. What are Paradoxes? How are they sometimes produced? How may a ball be made to roll up a sloping surface? Explain the principle involved, with Fig. 78. 173. Describe the experiment with the double cone, and explain the principle.

CHAPTER VII.

MECHANICS (CONTINUED).

THE MOTIVE POWER.—THE RESISTANCE.—THE MACHINE.—STRENGTH OF MATERIALS.

174. In a previous chapter we have treated of the Laws of Motion; we now proceed to consider the following practical points:—

I. The Motive Power, or Force by which motion is produced.

II. The Resistance to be overcome, or *work* to be done, which is always opposed to the Power.

III. The Machine, which is used by the Power in overcoming the Resistance, when it does not itself directly act.

IV. The Strength of the Materials employed.

In the case of a steamboat, steam is the Power by which motion is produced; the weight of the boat is the Resistance, which constantly opposes the Power. Since steam can not be directly applied in such a way as to move the boat, a Machine is used to aid in overcoming the Resistance; and this Machine is the engine. On the strength of the materials employed depend the usefulness and safety of the whole.

Motive Powers.

175. The chief powers used by man in producing motion are gravity, the elastic force of springs, his own strength, the strength of animals, wind, water, and steam.

176. *Gravity.—Springs.*—Gravity is applied by attaching weights to machinery, which they keep in motion by their constant downward tendency, as in certain kinds of

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174. What four subjects connected with Mechanics are treated of in the present chapter? In the case of a steamboat, what is the power? What, the resistance? What, the machine? On what does the usefulness of the whole depend? 175. Name the chief powers employed by man in producing motion. 176. How is gravity ap-

clocks. When the weight descends so far that it reaches a support, the machinery ceases to move, and is said to "run down". When there is no room to use weights, springs are often substituted for them, as in the works of watches. A spring is made of steel, or some other elastic substance; which, being bent, produces motion by a constant effort to unbend itself.

177. *Strength of Men and Animals.*—With his own strength man can produce a certain degree of motion, but not such as accomplishes the grandest results. From the strength of animals he derives important assistance. Even rude nations tame the animals around them, and turn their strength to account. The American Indians, when first discovered, had not learned to do this; and therefore, like other savages who rely entirely on their own strength, they had made no great advance in agriculture, manufactures, or any other branch of industry.

The horse is the animal whose strength is most widely and advantageously used. For continued labor, one horse is considered equal to five men. A horse of average strength can draw a load of a ton, on a good road, from 20 to 25 miles a day.

178. *Wind and Water.*—Still more powerful forces are found in wind and water, which are extensively used as moving powers by all civilized nations.

The wind is brought to bear, not only on the sails of vessels, but also in mills used for grinding grain, sawing wood, raising water, expressing oil from seeds, &c. Such machines are called Wind-mills; they were introduced into Europe from the East, about the time of the Crusades. The great objection to the wind as a moving power, is its irregularity, for in still weather the machines it moves are useless.

Water is a very powerful and useful agent. A little stream is often a

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plied? When is the machinery said to run down? When there is no room to use weights, what are often substituted for them? How does a spring produce motion? 177. What is said of the strength of man as a source of motion? What, of the strength of animals? What animal is most widely used? To how many men is one horse considered equal? As regards drawing, what is a day's work for a horse of average strength? 178. What sources of motion are still more powerful? How is the wind brought to bear? What are machines moved by the wind called? Whence and when were wind-mills introduced into Europe? What is the great objection to

source of prosperity and wealth to an extensive region. Affording what is called "water-power", it moves huge machines, and thus affords the means of manufacturing easily and cheaply. Water was first used as a motive power by the Romans, in simple machines for grinding grain, about the commencement of the Christian era. It is now applied in various kinds of machines, for sawing, spinning, weaving, grinding, &c. Though a stream may run so high in spring and so low in summer as to be useless for a time, there is far less difficulty from these causes than from the irregularity of the wind.

179. *Steam.*—The greatest of all the powers employed by man is STEAM, or the vapor generated by submitting water to a high degree of heat. Steam being an elastic fluid, its properties and applications will be considered hereafter.

180. The uses of steam were unknown to the ancients; it was not till near the close of the seventeenth century that its importance began to be realized. Its application to machinery marks an era in the world's history, and has invested man with immense power over matter. Driving the boat and car, it bears him what was once a day's journey in an hour. Applied in countless varieties of machines, it is the means of supplying us with thousands of comforts unknown to our forefathers. The farmer is indebted to it for his spade, hoe, rake, scythe, ploughshare, and all his implements. It helps to make the shears with which he cuts the wool from his sheep, and then cards the wool, and weaves it into cloth. It separates his cotton from its seed, and turns it into muslin and calico. It aids the builder by making his tools, forging his nails and bolts, moulding his ornaments, polishing his marble, cutting his stone, and sawing his wood. It supplies our parlors with furniture, our kitchens with cooking utensils, our dining-rooms with glass and china, knives and forks. It knits, twists, washes, irons, dyes, gilds, grinds, digs, and prints; and hardly any work of art meets our eyes, in making which steam has not been directly or indirectly used. It does all this, moreover, with wonderful precision and rapidity. The pyramids of Egypt, we are informed, kept 100,000 men at work twenty years in their erection. It has been computed that one powerful steam-engine would have done as much work in the same time as 27,000 of these Egyptians.

The Resistance.

181. Whatever opposes the Power is called the Resistance.

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the wind as a moving power? What is said of water-power? By whom and when was it first used? For what purposes is it now employed? What are the disadvantages of water as a moving power? 179. What is the greatest of the powers employed by man? What is Steam? 180. When did its importance begin to be realized? What has been the result of its application to machinery? Enumerate the different articles which steam is constantly employed in producing. What interest-

182. The resistance is not always of the same character. It may be a weight to be lifted, as a pail of water from a well; or a body to be moved onward, as a train of cars; or a wheel to be turned, as in a mill; or particles to be compressed, as in packing cotton in bales; or cohesion to be overcome, as in splitting a log of wood. As the most usual form in which the resistance appears is that of a weight to be moved, the term Weight is often used instead of Resistance, with reference to work of any kind, or whatever opposes the moving power.

183. UNITS OF WORK.—The efficiency of a force is estimated by the resistance it can overcome, or the amount of work it can do. In order to compare different forces, we must have a uniform *unit of work.*

The unit of work adopted is the resistance encountered in raising one pound through the space of a foot. Hence, to raise a body any distance constitutes as many units of work as there are pounds in the body multiplied by the number of feet in the given distance. To raise 2 pounds of water from a well 6 feet deep, is equivalent to twice 6, or 12, units of work. To lift a load of 1,000 pounds 10 feet involves 10,000 units of work.

184. HORSE-POWERS.—In estimating large amounts of work, it is customary to use *horse-powers* as a measure. A horse can perform 33,000 units of work, that is, can raise 33,000 pounds a foot, in a minute. An engine, therefore, that can perform 33,000 units of work in a minute is said to be an engine of one horse-power; one that can do 66,000 units of work in a minute is an engine of 2 horse-powers; and so on. Hence the following

Rule.—To find the horse-power of an engine, divide the number of pounds it is capable of raising one foot in a minute by 33,000.

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ing fact is stated with respect to the pyramids of Egypt? 181. What is the Resistance? 182. Mention some of the different forms in which the resistance appears, and give examples. What term is often used instead of *resistance*, and why? 183. How is the efficiency of a force estimated? To compare different forces, what is it necessary to have? What is the unit of work generally adopted? Give examples.

185. FRICTION.—The effect of the moving power is often diminished by Friction.

Friction is the resistance which a moving body meets with from the surface on which it moves.

If all surfaces were perfectly smooth, there would be no friction; but even those bodies that seem the smoothest are really covered with minute projections and depressions. These fit into each other, and a certain degree of force is required to raise the projections of the one surface over those of the other. With the naked eye we can not detect any unevenness on plate glass or polished steel; yet, if we view either through a microscope, we find that its surface is far from smooth, and hence there is some friction even when these substances are rubbed together.

186. Friction opposes motion in two ways:—

1. By increasing the resistance, as when a weight is dragged over the ground.

2. By diminishing the force before it is applied to the resistance; as in machinery, which sometimes loses as much as one-third of its power by the rubbing of its different parts against each other.

In estimating the working power of a machine for practical purposes, it is necessary to make allowance for the loss occasioned by friction; but, in merely investigating the principles of Mechanics and the construction of machines, we proceed as if the surfaces concerned were perfectly smooth, and no such thing as friction existed.

187. *Kinds of Friction.*—There are two kinds of friction:—

1. Sliding Friction, produced when a body slides on a surface, like the runners of a sleigh.
2. Rolling Friction, produced when a body rolls on a surface, like the wheels of a wagon.

188. Between any given surface and moving body, sliding friction is much greater than rolling friction. Hence we roll a barrel of flour over the ground instead of drag-

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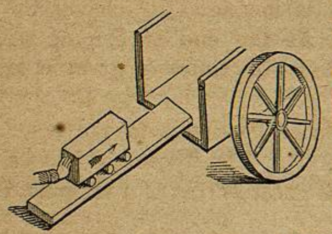
184. How are large amounts of work estimated? What is meant by a *horse-power?* Give an example. How may the horse-power of an engine be found? 185. By what is the effect of the moving power often diminished? What is Friction? How is it that friction is exhibited even between surfaces that appear smooth? Give an example. 186. In how many ways does friction oppose motion? Mention them. When is it necessary to make allowance for friction, and when not? 187. How many kinds of friction are there? Name them, and tell how each is produced. 188. Between any

ging it, and place a weight that is to be moved in a cart, or suspend it between wheels, instead of harnessing a horse directly to it.

On the same principle, we place rollers under a block of marble, and fasten castors, or small wheels, to the legs of heavy pieces of furniture. Rollers are also used with advantage in pushing a ponderous packing-box up an inclined plane into a cart, as shown in Fig. 80. In all these cases, sliding friction is converted into rolling, and the resistance is thus diminished. The larger the wheels and rollers employed, up to a certain limit, the greater the gain; but even small ones materially lessen the friction.

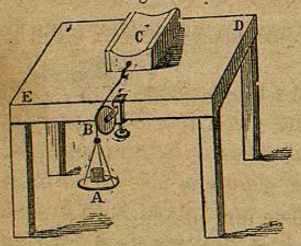
Fig. 80.



Rolling friction, on the other hand, may be converted into sliding. This is done when the wheels of a heavily loaded stage or wagon descending a steep hill are *locked*, that is, prevented from turning by an apparatus provided for the purpose. The resistance is thus increased to such a degree that the load can descend in safety. On the same principle, *brakes* are applied to the wheels of cars, to stop them the sooner.

189. *Laws of Friction.*—Several important laws relating to friction have been settled by experiments. In making these, the apparatus represented in Fig. 81 has been used. D E is a table, on which rests the block C. A string, passing over the pulley B, connects this block with a scale, A. By putting weights in the scale till the block moves, we are enabled to measure its friction; and, by making the block of different materials, varying its size and surface, and allowing it to remain a longer or shorter time on the table, the following laws have been established:—

Fig. 81.



1. The friction of a body is greater when it commences moving than after it has been moving for a time. Thus it

given surface and moving body, how does sliding friction compare with rolling friction? Mention some familiar cases in which we convert sliding into rolling friction, to lessen the resistance. What is said of the size of the wheels and rollers employed? In what cases is rolling friction converted into sliding? 189. How have the facts relating to friction been settled? Describe the apparatus employed for this purpose. When is the friction of a body greatest? Between what bodies and surfaces is fric-

takes a heavier weight to start the block C than it does afterwards to keep it in motion.

2. Friction is greater between soft bodies than hard bodies, and between rough surfaces than smooth ones. A sled that can hardly be moved over a newly ploughed field, is drawn without difficulty over a frozen pond.

3. In many cases, friction is increased by letting the surfaces remain in contact. At the end of five or six days, it has been found to be fourteen times as great as at first.

4. Between the same surfaces, friction is proportioned to the weight of the moving body. The friction of a block weighing 20 pounds is twice as great as that of a ten-pound block.

5. Within certain limits, friction is not increased by extent of plane surface. As long as the weight of a body remains the same, its friction will not vary, whether it rests on a larger or smaller base. In Fig. 81, the block C has its upper side hollowed out, so that, if turned over, it will rest merely on two ridges; yet the friction will be the same when it rests on that side as on the other.

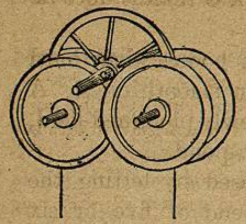
190. *Modes of Lessening Friction.*—No means has yet been found of doing away with friction altogether; but it may be lessened in three ways:—

1. By smoothing and polishing the surfaces.

2. By putting grease or some other *lubricant*, as it is called, between the surfaces. This fills up their depressions. Finely powdered plumbago (the common black-lead used in pencils), dry for wooden surfaces and mixed with grease for metallic ones, is one of the best articles used for this purpose. The wood-sawyer greases his saw to make it move easily, and cartmen and carriage-drivers keep the

tion greatest? In many cases, how may friction be increased? Between the same surfaces, to what is friction proportioned? What effect is produced on the friction of a body by increasing its surface? Exemplify this with the figure. 190. Can friction be entirely removed? In how many ways may it be lessened? What is the first of these? What, the second? What article makes one of the best lubricants? By whom are lubricants used? How may the friction of a wheel be diminished? What

Fig. 82.



FRICTION WHEELS.

axles of their wheels well covered with some lubricating preparation.

3. The friction of a wheel may be diminished by making its axle, that is, the cylinder running through the centre, turn on the circumferences of two other wheels at each end, as shown in Fig. 82. Such wheels are called Friction Wheels. They are used in delicate machinery.

191. *Uses of Friction.*—Though friction occasions a great loss of power, it is not without its beneficial effects. A river is prevented from rushing madly through its channel by the friction of its waters on its banks and bed. A tempest gradually loses its force by the friction of the air against the projections on the earth's surface. It is friction that prevents the fibres of wool, hemp, and cotton, when twisted together, from slipping on each other and giving way. Without friction nails would be useless, for they would draw right out; the wheels of a carriage would turn on the ground without moving it forward; and neither man nor beast could walk. It is the friction of our feet on the ground that enables us to take steps: when the friction is lessened, as on smooth ice, we walk with difficulty; were there no friction, we should find it impossible to walk at all.

Machines.

192. Machines are instruments used to aid the Power in overcoming the Resistance.

193. Simple machines used by the hand, are called Tools; as, the chisel, the saw.

194. Machines of great power are called Engines; as, the steam-engine, the fire-engine.

195. Machines merely aid the power in its action; *they can not create power.* This follows from the inertia of matter. The mightiest engine, therefore, remains at rest until acted on by some motive power; and, when thus acted on, it can not increase the power in the smallest degree, but on

are such wheels called? 191. Mention some of the beneficial effects of friction. 192. What are Machines? 193. What are Tools? 194. What are Engines? 195. What do machines merely do? Why can not a machine increase the power? Illustrate this principle in the case of a man who can raise 100 pounds of coal a minute from a

the other hand diminishes it, more or less according to the friction of its parts.

If a man standing over a pit 100 feet deep can, in the space of a minute, just pull to the top a tub containing 100 pounds of coal, no machine can enable him to raise a single pound more in the same time. By using pulleys, he may, to be sure, raise 600, 800, or 1,000 pounds at a time, but it will take him 6, 8, or 10 times as long as before; and, therefore, in the same time he will do no more work than with his hands alone—but less, on account of the friction of the pulleys. So, a certain amount of steam, just capable of performing 50,000 units of work in a minute, can not by any machinery be made to perform a single additional unit of work in the same time. Hence the great universal law which follows:—

196. *What a machine gains in amount of work, it loses in time; and what it gains in time, it loses in amount of work.*

Let us apply this law. A quantity of steam capable of moving 50,000 pounds a foot in a second, may be made to move 100,000 pounds a foot, but it will be two seconds in doing it; or it may move the weight a foot in half a second, but in that case it will move no more than 25,000 pounds. Under no circumstances can there be a gain in units of work without a corresponding loss of time, or a gain in time without a corresponding loss of units of work.

197. Perpetual Motion.—By Perpetual Motion is meant the motion of a machine, which, without the aid of any external force, on once being set in operation, would continue to move forever, or until it wore out.

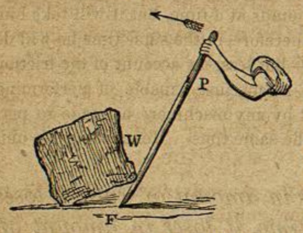
Such a machine many have tried to invent, but without success. Friction and the resistance of the air are constantly opposing the action of machinery; and as matter, on account of its inertia, can generate no power that will compensate for this loss, every machine must in time come to rest, unless some external force, such as wind, water, or steam, keeps acting upon it. Hence Perpetual Motion is impossible.

198. Advantages of using Machinery.—If no additional power is generated by machinery, but there is an actual loss from the friction of its parts, why is it employed? —Because in other respects its use is attended with important advantages, among which are the following:—

pit 100 feet deep. Give another illustration. 196. What is the great universal law of machines? Apply this law practically. 197. What is meant by Perpetual Mo-

1. Machinery enables us, with a certain amount of power, by taking a longer time, to do pieces of work that we could not otherwise do at all.

Fig. 83.



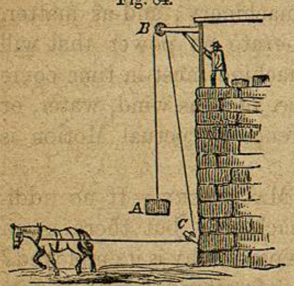
Thus, a farmer with a crow-bar, as shown in Fig. 83, can move a rock which with his hands alone he could not stir. With the aid of two other men, he could carry it or push it where he wanted, in one-third of the time that he could move it there alone with the crow-bar; but he may not have two others at hand to help him.

With machinery 10 men may do the work of 1,000. Of course it will take them 100 times as long; but this loss of time is of little consequence, compared with the difficulty of getting a thousand men together and placing them so as to work without interfering with each other. Some heavy pieces of work are of such a nature that but few laborers can get around them at a time; in these cases, unless the work can be divided, which is not always possible, it must remain undone without the aid of machinery.

2. Machinery enables us to use our power more conveniently.

The farmer removes a rock from his field with less difficulty and fatigue by means of a crow-bar than if he stooped over to lift it with his hands. The porter with his block and tackle hoists a box of goods to a loft with far greater ease than he could push or carry it up. The apparatus he uses enables him to hoist the load by pulling down upon a rope, and when pulling down his weight aids his strength.

Fig. 84.



3. Machinery enables us to use other motive powers besides our own strength.

A horse without machinery can not lift a weight; but he does it readily with the aid of the simple apparatus shown in Fig. 84. Steam, applied directly to a boat, can not move it forward; it is only with the help of machinery that it causes the wheel to revolve and thus produces motion. Here, as in all other cases, the

tion? Show that perpetual motion is impossible. 198. If no additional power is generated by machinery, why is it used? What is the first advantage of using machinery? Give an example. If, with machinery, 10 men can do the work of 1,000, how long comparatively will it take them? In some pieces of work, what difficulty pre-

power *is not created* by the machinery, but merely *transmitted* in a way to make it effective.

Strength of Materials.

199. There is a limit to the power of all machinery; and this limit is the strength of the materials of which it is made. Machines that work well in small models sometimes utterly fail when made of full size, because, when the resistance is increased and their own weight is added, no material can be found strong enough to stand the strain.

Nature, also, recognizes this limit of size. Animals, after attaining a certain age, cease to grow. If they kept on growing, they would soon reach such a size and weight that they could not move. If there were an animal much larger than the elephant, it would stagger under its own weight, unless its bones and muscles were thicker and firmer than any with which we are now acquainted. Fish, on the contrary, being supported by the water, move freely, no matter how heavy they may be. Whales have been found over 50 feet long and weighing 70 tons—a monstrous size and weight, which no land animal could support.

200. To determine how great a strain given materials will bear, and how they may be put together with the greatest advantage, becomes an important question in Practical Mechanics. The relative strength of different substances has been treated of under the head of Tenacity, on page 23. The following general principles relating to rods, beams, &c., should be remembered.

1. Rods and beams of the same material and uniform size throughout, resist forces tending to break them in the direction of their length, with different degrees of strength, according to the areas of their ends.

Let there be two rods of equal length; if the areas of their ends are respectively 6 and 3 square inches, the one will bear twice as great a weight

sents itself? What is the second advantage of using machinery? How is this exemplified in the case of the farmer? How, in the case of the porter? What is the third advantage gained by using machinery? Illustrate this in the case of a horse. In the case of steam. In both of these cases, what does the machinery merely do? 199. What limit is there to the power of all machinery? Why do machines often fail, though small models of them work well? Show how nature recognizes a limit of size. How is it that fish can move, though much larger and heavier than land animals? 200. What important question is presented in Practical Mechanics? What is the first principle laid down respecting rods and beams? Give an example. When a rod is very long, without breaking as the other. This law applies, no matter what the shape of the rods may be.

2. When a very long rod is suspended vertically, its upper part, having to support more of the weight of the rod than any other, is the most liable to break.

3. The strength of a horizontal beam supported at each end diminishes as the square of its length increases.

If two beams thus placed are respectively 6 feet and 3 feet long, the strength of the shorter will be to that of the longer as the square of 6 to the square of 3,—that is, as 36 to 9, or 4 to 1.

4. A horizontal beam supported at each end, is most easily broken by pressure or a suspended weight in the middle, and increases in strength as either end is approached. If, therefore, a beam of uniform strength is required, it should gradually taper from the middle towards the ends.

5. A given quantity of material has more strength when disposed in the form of a hollow cylinder than in any other form that can be given it. Nature constantly uses hollow cylinders in the animal creation, as in bones and the tubes of feathers; and the artisan, imitating nature, employs it in many cases where strength and lightness are to be combined.

EXAMPLES FOR PRACTICE.

1. (*See* §§ 183, 184.) What is the horse-power of a steam-engine that can do 1,650,000 units of work in a minute?
2. What is the horse-power of an engine that can raise 2,376 pounds 1,000 feet in a minute?
3. What is the horse-power of an engine that can raise 1,000 pounds 2,376 feet in a minute?
4. A fire-engine can throw 220 pounds of water to a height of 75 feet every minute; what is its horse-power?
5. A cubic foot of water weighs $62^1/_2$ pounds. How many horse-powers are required to raise 200 cubic feet of water every minute from a mine 132 feet deep?

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what part of it is most likely to break? What law is given respecting the strength of a horizontal beam supported at each end? Give an example. In what part is a horizontal beam supported at each end most easily broken by pressure? What shape gives a beam uniform strength? In what form must a given quantity of material be disposed, to have the most strength?

6. A locomotive draws a train of cars, the resistance of which (caused by friction, &c.) is equivalent to raising 1,000 pounds, 15 miles an hour; what is its horse-power?
   [*Find how many feet the locomotive draws the train in a minute, and then proceed as before.*]
7. How many pounds can an engine of 10 horse-powers raise in an hour from a mine 100 feet deep?
8. A certain man has strength equivalent to $^1/_8$ of one horse-power; how many pounds can he draw up in a minute from a pit 25 feet deep?
9. (*See* § 189, *Fourth Law.*) If the friction of a train of cars weighing 50 tons, on a level railroad, be equivalent to a weight of 500 pounds, what will be the friction of a train weighing 25 tons? of one weighing 100 tons? of one weighing 60 tons?
10. (*See* §§ 195, 196.) C can just draw 75 pounds of coal a minute out of a mine. With the aid of a system of pulleys, he can raise 225 pounds at a time; the friction being equivalent to 75 pounds, how many minutes will he be in raising the load?
    [*In practical questions of this kind, the friction must be added to the resistance.*]
11. With a certain machine, one man can do as much as eight men without the machine. Allowing the friction of the machine to be equal to one-fourth of the resistance, how much longer will he be in doing a certain amount of work than they?
12. (*See* § 200.) [*The area of a rectangular surface is found by multiplying its length by its breadth; that of a triangle, by multiplying half its base by its perpendicular height.*] Which will support the greater weight without breaking, a joist whose section is 4 inches long by 5 broad, or one of the same kind of wood, 3 inches by 8?
13. Which, when suspended, will bear the greater weight without breaking, a square rod of iron whose end is 3 inches by 3, or a rod whose cross section is a triangle with a base of 6 inches and a perpendicular height of 2?
14. Two rods of copper, of equal length and uniform thickness, have ends respectively 4 inches by 2, and 17 inches by half an inch. Which, when suspended, will support the greater weight?
15. Two horizontal beams of the same material, breadth, and thickness, supported at both ends, are respectively 2 and 14 feet long. Which is the stronger of the two, and how many times?