## CHAPTER II.

Nature of heat—The mode of measuring it—Its effects on gases and water—General ideas of nature of heat—Old notions regarding it—Material theory and its refutation by Davy—Modern theory that heat is a form of energy—Definitions and examples of energy and work—Example of conversion of heat into work—Measurement of heat—Temperature—Thermometers, their graduation and defects—Quantity of heat—Specific heat—British thermal unit—Capacity of substances for heat—Relation between heat and work—The mechanical equivalent of heat—Joule's experiments—Effect of application of heat to gases—Nature of gas—Boyle's law connecting the pressure and volume of gas—Graphic representation of Boyle's law—Definition of an Isothermal—Charles's law connecting the volume and temperature of gas—Dalton's law connecting the volume and temperature of gas—The air thermometer—Absolute temperature—Combination of Boyle's and Charles's laws—The specific heat of gases—Difference in the specific heats according as the gas is heated at constant volume or at constant pressure—External and internal work done when a gas is heated at constant pressure—Effect of application of heat to water and ice—Heat absorbed in liquefying ice—Heat absorbed in evaporating water at various pressures—External and internal work of evaporation—Law connecting the pressure and temperature of steam—Total heat of steam analysed—Specific volume and relative volumes of steam—Law connecting the pressure, volume, and density of steam—Graphic representation of the expenditure of heat in evaporating water—Expansion of gas and steam—Isothermal expansion of gas—Isothermal expansion of steam—Adiabatic expansion of gas—Adiabatic expansion of steam.

In this and the following chapter it is not by any means proposed to go into the study of heat, otherwise than as it bears directly upon the heat engine. Consequently no reference will be made to theories and phenomena of heat, other than those which affect gases and water: nor will any attempt be made to describe the numerous experiments which are usually dwelt upon in treatises devoted exclusively to this branch of science. On the contrary, these chapters will be found to be mere summaries of certain

parts of the subject, inserted here because they are absolutely necessary to the correct knowledge of the heat engine.

Everyone is familiar with the sensations produced by heat on the human body, as, for instance, when the hand is exposed to the action of a fire, or plunged into boiling water. The agency which produces this sensation is called Heat. The nature of the agency has, ever since the physical sciences were first studied, been the subject of speculation with natural philosophers. In the last and the beginning of the present century, heat was supposed to be a kind of matter which differed from all other forms of matter with which we are acquainted, in that it had no weight. It was, in fact, supposed to be a subtle and imponderable fluid, which was capable of spreading and insinuating itself between all the elementary particles which constitute matter, and of flying from hot bodies to colder ones, no matter at what distance apart these bodies might be. This theory did good service in its time, in helping philosophers to account for many of the effects of heat; it had, however, ultimately to be discarded, because it failed altogether to account for the fact that heat, in apparently illimitable quantities, could be evolved from cold bodies, by rubbing them together; that is to say, by the process of friction, cold bodies could be made hot and could be made to communicate heat to any quantity of other cold bodies. This phenomenon was accounted for, by the believers in the material theory of heat, in the following manner: The bodies to be rubbed together possessed in their state of heat, or thermal condition, before the commencement of the experiment, a certain quantity of the fluid called heat, which caused them to be as hot as, say, for example, the human body. This was expressed by saying that the bodies when as warm as the human body had a certain capacity for heat, i.e. they required a certain quantity of the imponderable fluid to be absorbed between their particles, in order that they might become as warm as aforesaid. Now, when the bodies were rubbed together, and became eventually hotter than the human body, this was accounted for by saying that their capacity for heat became diminished by the action of friction ; that is to say, they could not, when rubbed, retain the same amount of the imponderable fluid as before, without becoming hotter. If any experiment could be devised which should prove that the capacity of bodies for heat is not diminished by friction, then the material theory of heat would fail to account for the fact that bodies become hotter when rubbed.

The first absolutely conclusive experiment, which established the fact that friction makes bodies hot, while it does not diminish their capacities for heat, was made by Davy in 1799. His experiment consisted in rubbing together two pieces of ice till they melted into water, due care having been taken to prevent heat from entering the ice by any other means than friction alone. Now, according to the old theory, the resulting water ought to have a less capacity for heat than the original ice ; but it has been proved over and over again by experiment that the capacity of water for heat is not only not less than, but about double that of ice ; consequently the material theory failed completely to account for the facts, and Davy, after reasoning on his experiments for some years, came to the following conclusion, which we repeat in his own words :—

'Heat, then, or that power which prevents the actual contact of the corpuscles of bodies, and which is the cause of our own sensations of heat and cold, may be defined as a peculiar motion, probably a vibration of the corpuscles of bodies tending to separate them.' Again, in 1812, Davy thus states his theory :—'The immediate cause of the phenomenon of heat, then, is motion, and the laws of its communication are precisely the same as the laws of the communication of motion.'

Another way of stating the above is that heat is a form of *energy*. To make this point clear before going further into the nature of heat, we must first define what is understood by the term *energy* and the involved term *work*, and illustrate the definitions by examples.

*Energy* is the power of doing work.

*Work* is the overcoming of a resistance through a certain space, and is measured by the amount of the resistance multiplied by the length of space through which it is overcome.

The simplest possible example of doing work is to raise a weight through a space against the resistance of the earth's attraction, that is to say, against the force of gravity. For instance, if a hundred pounds be raised vertically upwards, through a space of three feet, work is done, and, according to the above, the amount of work done is measured by the resistance due to the attraction of the earth or gravity, i.e. one hundred pounds, multiplied by the space of three feet, through which it is lifted. The product formed by multiplying a pound by a foot is called a foot-pound. Thus, in the above instance, the amount of work done is 300 foot-pounds. Had the weight been only three pounds, but the height to which it was raised been 100 feet, the quantity of work done would have been precisely the same, i.e. 300 foot-pounds.

In Great Britain, the unit of work is—a resistance, equal to the attraction of the earth upon a pound of matter, overcome through a space of one foot ; or, in other words, one foot-pound.

## RATE OF DOING WORK. HORSE-POWER.

The rate of work of any agent means the quantity of work which it performs in a given time, and is measured by the number of foot-pounds done in an hour, or a minute, or a second.

*A quantity of work equivalent to the raising of 33,000 pounds through one foot, in one minute, is called a horse-power.* This is the unit generally employed to represent the rate of work of a steam engine, and is adopted to avoid the use of the very high numbers which would result if foot-pounds per minute were chosen. Thus an engine which can overcome resistances equivalent to raising 10,000 pounds vertically upwards through 33 feet every minute is said to be an engine of 10 horse-power or 10 H.P. If the engine raised the same weight through the same height once every second, instead of every minute, then by the definition the work done would be equal to sixty times ten horse-power, or 600 H.P. Hence if $r$ = the resistance expressed in pounds, $h$ = the height in feet through which $r$ is overcome, and $t$ = the time in minutes which it takes to do the work, then

$$\text{The horse-power exerted} = \frac{h \times r}{33{,}000 \times t}.$$

The lifting of weights is only one special form of doing work, but there are also many other ways of doing it. For example: if a carriage be pulled along a level road, it is well known that its progress is resisted by the friction of its wheels against the surface of the road and against their own axles. Hence the pulling of such a carriage answers perfectly to the definition of doing work, for resistance is thereby overcome through a space.

Again, it is well understood by those who have studied the laws of motion that if a mass—as, for example, a stone—be projected upwards it will rise to a certain height, depending on the velocity with which it left the hand. The exact height to which it will rise is precisely equal to the height through which it must fall, under the action of gravity, in order that, at the end of its fall, it may have acquired a velocity equal to that with which it was projected upwards. Now the imparting of this velocity to the mass is evidently a way of enabling work to be done, for the mass is thereby caused to rise to a certain height, against the attraction of the earth, and the amount of the work done is measured by the weight of the mass multiplied by the height to which it rises.

It is not necessary to impart velocity to the mass in a vertical direction only, in order to do work. Whenever motion is given to a body in *any* direction the resistance due to the inertia of the body is overcome through a space, and consequently, by the definition, work is done. If, for instance, a train were capable of moving without friction on a level railway, in order to start it from a state of rest and give it a speed of, say, forty miles an hour, work would have to be done in order to overcome the mere inertia of the train. When once the given speed had been imparted to the train, it would, of course, move on for ever on a level railroad, provided it met with no frictional resistances. If in its course it came to an inclined plane, it would run up the plane till it had attained a vertical height above the level equal to the height through which the train must fall downwards, in order to attain the given speed of forty miles an hour. The measure of the work done in giving motion to the train is equal to the weight of the train multiplied by this height.

On actual railroads the work done by the engine partakes of the character of each of these examples. When starting the train from a station and giving it a certain speed, the resistance due to the inertia of the whole moving mass is overcome. The going up an incline corresponds to lifting a weight up a height; and throughout the entire run the friction of the wheels and axles and the resistance of the air are being overcome.

## ENERGY.

It has been necessary to dwell thus at considerable length on the nature of Work, in order that the term Energy, i.e. the power of doing Work, might be thoroughly understood. This power of doing work exists in many different ways. For instance, a coiled spring is capable of doing work in driving a clock, and therefore possesses energy. Similarly a weight raised to a height, and attached to a string passing over a pulley, is capable, during its fall, of raising another weight, or of driving machinery, and consequently it also possesses energy. Again, a body in motion, such, for instance, as a railway train, is capable of overcoming the friction of the brakes for a certain time till it is brought to a standstill, and therefore possesses energy. Similarly a projectile from a modern rifled gun possesses very great energy owing to the high speed at which it moves, so much so that before it is forcibly brought to a rest it can do work represented by piercing many inches of iron armour. It will be noticed that there is a great difference between the kind of energy of which the first two cases are examples and the last two. The first two are instances of bodies which, though themselves at rest, are capable at any moment of doing work. In the case of the coiled spring its energy was due to the relative position of its parts with regard to each other and to the mutual forces acting between them. In the case of the raised weight, its energy was solely due to its position with regard to the earth and to the forces acting between the earth and it. This energy, due to position, is called potential energy, a term which signifies that the energy is *capable* of being exerted. The last two instances on the contrary are cases of bodies possessing energy by virtue of their motion. This kind has been called actual or kinetic energy. The last term, which is derived from a Greek word signifying motion, is, perhaps, the most appropriate of the two.

Bodies may be possessed of both descriptions of energy at one and the same time. For instance, when the raised weight of the former example begins to fall, it possesses kinetic energy by virtue of the motion which it has acquired, while it still possesses potential energy, for it is capable of falling further still. For every foot which it descends its kinetic energy increases, while the potential diminishes. Just as it touches the earth its kinetic energy is a maximum, while the potential has vanished altogether. Thus during the fall the energy has changed from being all potential into being all kinetic. Moreover, the kinetic energy acquired at the end of the fall is exactly equal in amount to the potential energy possessed at the commencement. For, before its fall the mass was capable of pulling up another mass of nearly equal weight with itself, to the same height above the ground which it occupied; while at the end of the fall it has acquired a velocity, sufficient, if reversed, to send itself back to whence it came. Moreover, it is clear that at any time during the fall, the sum of the potential energy left, and the kinetic energy acquired, are equal to the original energy, for what the one has lost in amount the other has gained.

This is an example of what is called the *transmutation of energy*, by which is meant that the energy is changed from one form into another, and also of the *conservation of energy*, by which is meant that the total energy of the two bodies—viz. the earth and the weight—is not altered in amount, but only in kind. It is one of the cardinal doctrines of modern science, and one which has done more to extend our knowledge of heat than any other, that energy, like matter, can neither be created nor destroyed by material agency, but can only be transmuted from one form to another. This doctrine is called the Principle of the Conservation of Energy. In books on Dynamics, the principle is proved by mathematical reasoning to be true for certain cases, and it has, moreover, been proved by experiment to be true in all cases which can be tested by experiment. Hence it is believed to be universally true. The following is a general statement of the principle.

The energy of any system of bodies cannot be altered in quantity by the mutual action of the bodies; it can only be transmuted in kind into one or more of the forms which energy takes.

We are now in a position to return to the subject of Heat, and to understand how it is that heat is a form of energy—i.e. a form of the capability of doing work. For Davy's statement is, that heat may be defined to be a peculiar motion of the corpuscles of bodies; now, we have seen that matter in motion is capable of doing work, and is therefore possessed of energy, and consequently if heat be motion, or the cause of the motion of the ultimate corpuscles of matter, heat is also a form of energy.

## HEAT A FORM OF ENERGY.

The reasons for believing that Davy's definition of heat is a true one are the following:—

1. It seems impossible to believe that heat is a substance; for if it be such, then no theory has yet been advanced which can account for certain phenomena, such for instance as the production of heat from bodies in boundless quantities by means of friction or other mechanical action.

2. Heat can always be generated by doing work upon bodies. For example, we have seen how Davy melted ice by friction. Again, let the student attempt to file a piece of metal, and after a very few strokes of the file, he will find that both it and the metal have become perceptibly warmer, and if he continues the action smartly for some time on a small piece of metal, he will not be able to touch it without burning his hand. As an example of another kind of mechanical action producing heat, it is well known that a smith can hammer a small piece of iron to a red heat. Again, if water be allowed to fall several times from a height into a nonconducting receptacle, and care be taken to prevent the escape of heat, it will be found that after its fall the water will be warmer than at the commencement of the experiment. Another and most important example is the effect of compression upon gases. If, for instance, a portion of air be inclosed together with a piece of easily inflammable tinder in a cylinder provided with a movable piston, and the piston be driven down suddenly, it will be found that the contained air has become so warm that it can cause the ignition of the tinder. Now in all the above instances, unless we are prepared to admit that energy is destructible, that is, that it can be put out of existence altogether, we are forced to confess that it is merely transmuted into heat, for heat is apparently the only thing we have to show for the energy expended in the majority of these examples.

3. The converse of the above is also true, viz. heat can be made to produce work, and for every unit of work which it does, a certain amount of heat disappears, and there is nothing to show for the disappearance of the heat but the work done. As an example of this, we need only refer to the elementary steam engine described in the first chapter, where we saw that the heat of the fire, communicated to the water contained in the cylinder, was partially converted into work done; for by the agency of heat alone the piston with its weights was raised to a certain height. The conditions of this experiment were not such as to enable us to ascertain what heat, if any, had disappeared in consequence of the work done; but the following modification of the experiment will render this fact also demonstrable.

Instead of holding water, let the cylinder contain a portion of air of a certain warmth, and let the piston, instead of being loaded with common weights, have a vessel containing a quantity of water placed on it. Then, so long as the weight on the piston remains constant, and so long as no heat is communicated to the gas from outside, nothing will happen.

If, however, a little of the water be removed from the can, the pressure of the inclosed air will cause the piston with its load to rise through a small space, and again come to rest. For, the air occupying a larger space in the cylinder, its pressure becomes diminished by a well-known law, which will be explained hereafter (see page 43), and as soon as this diminished pressure on the bottom of the piston is equal to the diminished pressure of the piston on the inclosed air (caused by some of the water having been taken away) then the whole must come to rest. Let now a little more water be abstracted; the piston will rise a little higher, and so on, till the whole of the water has been removed, when the piston will have risen higher still. A convenient way of abstracting the water, as fast or as slowly as we like, is by means of a syphon. If now we have any means for ascertaining the warmth of the air at the beginning and at the end of the experiment, it will be found to have lost heat at the end, after having done work, measured by lifting the piston, together with the pressure of the external atmosphere and the empty can through the whole height, and different portions of the water through different heights. Now, unless this heat has been spent in effecting internal changes in the constitution of the gas itself, it must have been spent in doing the above work, for no other effects have been produced. It is of course assumed that in the experiment no heat has been allowed to escape from the air in the cylinder to external bodies, or, *vice versâ*, to reach the air from external bodies.

Most elaborate experiments have been made on steam-engines when at work, in which the following quantities have been measured:—1. All the heat which enters the engine in the shape of steam; 2. All the heat which leaves the condenser in the shape of warm water; and 3. All the heat which escapes during the working of the engine in various ways; and it has been found that the quantities comprised under the 2nd and 3rd headings are not equal to but less than the heat which enters the engine; so that a certain quantity remains to be accounted for, the disappearance of which can only be explained on the supposition that it has been turned into the mechanical work done by the engine.

From all the above considerations we conclude that heat is a form of energy. It is further supposed that the special form which this energy takes is that of a motion of the molecules which constitute matter. Into the nature of this motion, however, it is not proposed to enter here.

The next thing which we shall want to know is this: What is the exact relation between heat and work; that is to say, What quantity of heat can be produced by the doing of a certain quantity of work, and, *vice versâ*, How much work is a given quantity of heat capable of doing? Before it is possible to answer these questions, it must first be explained what is meant by a quantity of heat, and how heat is measured at all.

### MEASUREMENT OF HEAT. TEMPERATURE.

Everybody is familiar with the sensations caused by different *intensities* of heat. For instance, the sensation produced by plunging the hand into boiling water is very different from that caused by contact with cold water taken direct from a well. The quality of heat which causes these sensations is called *temperature*. In the first case the immediate cause of the sensation experienced was the heat leaving the boiling water and entering the comparatively cold hand; while in the second instance exactly the reverse took place, heat entering the cold water from the comparatively warm hand. This communication of heat from one body to another depends on the differences between their temperatures; so much so that temperature has been defined as follows: 'The temperature of a body is its thermal state considered with reference to its power of communicating heat to other bodies.'[1]

If now two bodies be so placed that they can freely communicate heat to one another, and are isolated from the influence of all other bodies, then if neither of them loses heat they are said each to have the same temperature, but if one of them loses and the other gains heat, then the body which loses is said to have the highest temperature.

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[1] See Clerk Maxwell's *Theory of Heat*, p. 32.

Temperatures are measured and compared by noting the effects which heat has upon bodies. One of the most remarkable effects of heat is that it expands most substances to which it is communicated, so that the higher the temperature the greater the expansion. If then we want to compare the temperatures of two bodies, we have only to bring each of them in turn into thermal communication with some third substance which expands readily under the action of heat.

If care be now taken that each of the bodies in turn remains sufficiently long in contact with the third body, so that the latter may acquire, first, the exact temperature of one of them, and afterwards that of the other, and if its expansion in each case be carefully measured, then that body which causes the greatest expansion has the highest temperature. An instrument designed to serve the purpose of this third body is called a Thermometer.

## THERMOMETERS.

A thermometer for practical use should be portable, readily acted upon by slight differences of temperature, and difficult to put out of order; it should be furnished with an index, or scale, for reading off differences of temperature, and should always give the same reading on the scale, for the same temperature, under the same circumstances. Thermometers are made of various substances, but we propose at present to describe only the one which is in most common use, viz. the ordinary mercurial thermometer. This instrument (see fig. 10) is made by taking a tube of glass, a few inches in length, having a capillary bore, that is to say a bore of very small calibre. A bulb is blown at one end of the tube, and while the bulb is warm, so that most of the air it contains is expelled, the tube is plunged into mercury. The effect of this is to cool the tube, and, as we shall see afterwards, to reduce the pressure of the air which remains in the bore and bulb. Some of the mercury then enters the bore, and partly fills the bulb. By boiling this mercury while in the bulb, the remainder of the air is expelled, its place being taken by the vapour of mercury. If now the open end of the tube be again plunged into mercury, both tube and bulb will be completely filled, and while still warm the open end is closed hermetically. As soon as the tube and its contents have cooled down, the mercury will be found to have contracted, leaving part of the bore quite empty. The instrument is now ready for graduation. This is done by first marking on the tube the position at which the mercury stands for two different temperatures, and then dividing the intermediate space into an arbitrary number of equal spaces, each of which is said to represent one degree of temperature. The two temperatures always chosen are those of melting ice and boiling water. The temperature of melting ice is always the same, at the varying pressures of our atmosphere. The thermometer is plunged into a mixture of melting ice and water, and, after remaining immersed for some time, the point at which the mercury stands is marked on the tube. We may be certain that we have thus marked the exact temperature of melting ice; for if, during the process of immersion, heat enters the mixture of ice and water, its effect will be simply to melt some more of the ice, and not to raise the temperature of the water. This action of heat will be explained

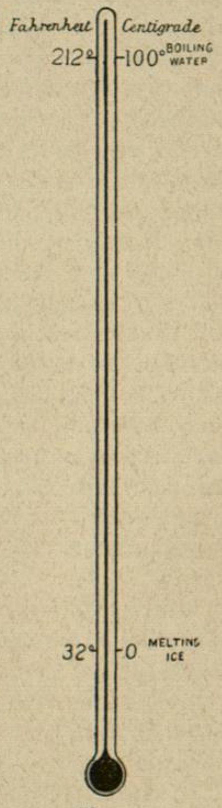

Fig. 10.

hereafter. It is more difficult to mark the point at which the mercury stands for boiling water, for it is known that water does not always boil at the same temperature. In fact, the greater the pressure under which the water boils, the higher will be its temperature. Consequently, on a day when the barometer stands high, boiling water is hotter than when the opposite is the case. It is therefore necessary to fix upon some one special atmospheric pressure in order to settle a standard boiling-point, and the pressure always adopted in this country is that marked by the barometer when the mercury stands at a height of 29·905 inches, the temperature of the mercury being that of melting ice. If then, on a day when the barometer indicates the above pressure, the thermometer be immersed in the steam of boiling water, it will be found that the contained mercury will rise to a certain point, and remain there; and by marking the tube at this place we obtain a point which always shews the temperature of boiling water at the standard pressure of the air. This temperature is always fixed and invariable, so long as the pressure under which the water boils remains fixed; for the effect of adding more heat to the water is only to turn more of it into steam, but not to raise its temperature. The reason of this will be explained hereafter.

Having now got two fixed points on the tube of the thermometer, we are at liberty to call them by any numbers we please, and to divide the space between them into any convenient number of divisions, or degrees, and to carry these divisions above the boiling and below the freezing points, as far as the length of the tube permits. There are three modes of numbering in common use in various countries:—

1. The Centigrade scale, in which the temperature of ice is called zero, or 0°, and the temperature of boiling water 100°. The space between these two is divided into one hundred equal parts, each of which, if the bore of the tube be perfectly even, is *assumed* to represent an equal increment of temperature, and the divisions are carried up above boiling-point, and down below freezing-point as far as the tube permits. Those degrees below freezing-point are called negative. This scale of temperature is in common use in nearly all the countries of the continent excepting Russia.

2. The Fahrenheit scale, used in the British Empire and the United States. On this scale the freezing-point is called 32°, the boiling-point 212°, and the intermediate space is divided into one hundred and eighty equal parts. The zero of this scale is 32° below freezing-point, and below this zero the numbers are negative.

3. The Réaumur scale is used chiefly in Russia. This scale differs from the Centigrade, in that the boiling-point is called 80°, and the space between it and zero or melting ice is divided into eighty equal parts. This scale is less in use than either of the others. Throughout this book the Fahrenheit scale is the one generally referred to. Whenever the Centigrade scale is made use of, it will be specially indicated by writing C. after the numeral showing the number of degrees. Fig. 10 shows the scales of the Fahrenheit and Centigrade thermometers side by side.

To compare degrees on the Fahrenheit and Centigrade scales it is only necessary to remember that the freezing-point on the Fahrenheit scale is 32°, and on the Centigrade 0°, while the number of degrees between this and boiling-point is in the former case 180, and in the latter 100. Consequently the length of one degree F. is $\frac{5}{9}$ of one degree C. Now the actual number of degrees F. above freezing-point is equal to the number on the scale minus 32°. Let $T°$ stand for the number of degrees on either scale, then $T_C° = \frac{5}{9}(T_F° - 32°)$ and conversely $T_F° = \frac{9}{5}T_C° + 32°$.

It is not proposed to enter here into the refinements of thermometer-making, but it will be necessary now to point out how far the mercurial thermometer may and may not be trusted, as a measurer of temperature, and what errors are inseparably connected with its use, no matter how perfectly it may be made.

For the mere purpose of ascertaining whether two or more bodies are precisely of the same temperature, or for stating generally in which of them the temperature is highest, the instrument is trustworthy enough. It is only when it is wanted to measure the thermal condition of bodies *quantitatively* that its indications can no longer be accepted. For instance we cannot be certain that a difference of temperature of one degree between say 32° and 33° in any body measured on a mercurial thermometer represents the same difference in its thermal condition as does a difference of one degree between, say, 200° and 201°. In other words, if we heat a certain quantity of water from 32° to 33°, and a similar quantity of water from 200° to 201°, we cannot by any means state that we have in each operation altered the thermal condition of the water by the same amount.

There are two reasons for this. The first has to do with the thermometer, and the second with the substance of which the differences of temperature have to be measured. It will be remembered that the way in which the length of degrees was arrived at when making the thermometer was by dividing the space between freezing and boiling point into 180 equal divisions, each of which was called one degree of temperature. Now in order that each of these degrees should represent an equal increase of heat of the mercury we should have to prove that if we add successive equal quantities of heat to the mercury, we thereby expand it by each operation by an absolutely equal quantity. Now we have no right to assume that this is the case, for the action of heat in causing some bodies to expand is known to be most irregular. If, for instance, the thermometer had contained water instead of mercury, then, commencing at freezing-point, it is known that the first effect of increasing the temperature is to cause the water to contract. This contraction would go on till the water had reached the temperature of about 39°, after which further additions of heat would cause the water to expand. In the same way, careful experiments made with mercury have proved that its rate of expansion at high temperatures is considerably greater than at low ones, for equal increments of heat; consequently the errors in the high part of the scale become considerable.

The second reason has only to do with the substance the temperature of which has to be measured. Even assuming that our thermometer were quite perfect, we should still be unable to use it by itself alone to determine quantitatively the thermal condition of bodies; for the thermometer in the first instance shows only the temperature of its own mercury, and though its degrees might be so marked that each successive one would correspond with successive equal additions of heat to the mercury, still it does not follow that this would also be true of the substance whose temperature had to be ascertained. On the contrary, experiments on some substances, such as water, show that it takes more heat to raise their temperature by one degree at the high part of the scale than at the low part.

This last remark leads us at once to the object of all experiments on thermometry, viz. the measurement of quantities of heat. It might at first be supposed that the measurement of temperature was the same thing as the measurement of quantity of heat, but an easy experiment will prove that this is not the case. Take two vessels, one containing a pound of water and the other a pound of olive oil, each liquid having the temperature of the air of the room, say 55°. Take also two pieces of copper, each weighing a pound. For the purpose of the experiment sheet copper about one-sixteenth of an inch thick is best; and for convenience sake it should be bent round nearly to the form of a cylinder. Bring each of these pieces to a certain high temperature. This is best accomplished by boiling them for a short time in water, so that their temperature becomes 212°. Next, plunge one of the pounds of copper into the pound of