INTRODUCTION

Aim and Method of Physical Sciences

1. Physical Sciences.—The study of nature includes two great divisions, biological and physical sciences. The former includes those that involve the complex phenomena of life, while the latter are concerned with the investigation of the fundamental phenomena of matter. Physics and Chemistry are the fundamental physical sciences and form the basis upon which Astronomy, Geology and Meteorology rest in investigating their special realms in the world of nature. Formerly Physics was called Natural Philosophy, in distinction from Natural History which described the world of plants and animals.

Physics deals with the properties and phenomena of inanimate matter as affected by forces, and is expecially concerned with the properties common to all kinds of matter and those changes of form and state which matter undergoes without being changed in kind, as well as such general phenomena as sound, heat, electricity and magnetism. Chemistry is distinguished from Physics in that it is chiefly concerned with the phenomena that result when different kinds of matter are brought together and enter into combination. It deals largely with the qualities in which one kind of matter differs from another. There are, however, many points where these sciences merge into each other, and the domain of *physical chemistry* lies largely in this borderland.

2. The Aim of Physical Science.—It is the aim of physical science so to systematize our knowledge of the material world that all its phenomena shall be seen as special instances under a few far-reaching and more inclusive generalizations called laws. And when a given phenomenon is analyzed in this way into separate parts or phases each of which is but a special case under some general law, the phenomenon is said to be explained.

In seeking an explanation we determine the *causes* of the phenomenon in question; that is, the *essential* circumstances or those circumstances without which the given event does not occur; and then we seek to determine the effect of each of these circumstances separately, and exhibit, if possible, each such effect as a special instance under some general law.

For example, the complex motion of a ball struck by a bat is found to be dependent on the motion given to it by the blow of the bat, on the presence of the earth, and on air resistance.

We first try and determine how a body moves when set free in the presence of the earth without any initial blow or impulse and in a vacuum. We find in this way an unvarying rule of motion that applies to all bodies of whatever size or shape, and we call it the law of falling bodies. That part of the motion of the ball which depends only on the nearness of the earth is but a special instance under this law. Now, making allowance for the motion due to the earth, we seek to determine that part of the motion due to the initial blow, and here again we find that the actual motion seems to be exactly according to a general rule which is found to hold whenever an impulsive force acts on a mass. And finally we investigate the effect of air resistance, determining how it affects a body at rest and how it modifies the motion of a body moving through it, and here again certain general rules are found which apply not only to the special case under consideration, but to all cases of bodies moving through air. When the effects of all three circumstances are taken into account, the motion is found to be exactly accounted for, and is then said to be explained.

Leverrier and Adams, in analyzing the motion of the planet Uranus, found that after taking account of all the known circumstances, such as the attractions of the sun and other planets upon it, there still remained a part of its motion which was not accounted for, and assuming it to be due to an unknown planet they computed its position and mass, and thus the planet Neptune was discovered.

But in analyzing our problem we may go deeper and show that the motion of the ball near the earth is such as would result from a force urging the two bodies together, and we may then discover that it is merely a special instance of the law that all bodies are influenced by forces urging them together or, in other words, that all bodies attract each other. When we can show also that the forces between the air and the moving body are due to the motion given to the air and so are simply particular exhibitions of the general rule which holds whenever matter is set in motion, we feel that a still higher degree of understanding is reached.

By such a process all the complex facts of nature are assigned their places in an orderly system. But a limit is soon reached beyond which the mind cannot go, because thinking is conditioned by experience, and even in its profoundest theories and speculations the mind must employ those conceptions which it has obtained from the world about it.

3. Experiment.—Physics is an experimental science, its generalizations rest solely upon experiment, and although reasoning upon established facts has often led to the discovery of new truths of great importance, the final appeal must always be to experiment. If the deduction is thus disproved, it appears either that the reasoning was wrong or that there are certain elements entering into the problem that were neglected. In seeking for the causes of such discrepancies new truths have often been discovered.

An experiment is a combination of circumstances brought about for the purpose of testing the truth of some deduction or for the discovery of new effects. The usual course of an experimental inquiry is to modify the circumstances one by one, noting the corresponding effect until the influence of each is thoroughly understood.

4. Necessary Assumptions.—In every experimental science it is assumed that the same causes always produce the same effects and that the position of the event as a whole in either time or space only affects the absolute time and position of the result, provided there is no change in the *relative* time or space relations of the various circumstances involved. For example, if all the other circumstances are the same, a stone will fall in exactly the same manner next week as it does to-day, or if the solar system be changing its place in space no change in the manner of the stone's falling will take place from that cause alone.

Experience up to this time has justified these assumptions, and without them progress in physical science would be impossible.

FUNDAMENTAL CONCEPTIONS

5. Force.—Our ideas of force are derived primarily from muscular effort. It requires an effort to lift a weight, to throw a ball, or to compress a spring. The upward pull upon a weight at any instant while it is being lifted is a force acting on it, and the downward tendency of the weight which the pull opposes is also a force.

Anything that serves to accomplish what would require muscular exertion to bring about exerts a force. Thus a support exerts a force on the weight which rests upon it, and the weight exerts an equal and opposite force on the support, compressing it. A bat exerts a force against a ball in giving it motion, a clock spring exerts a force against the stop that prevents it from unwinding.

6. Matter.—Through our muscular sense and sense of touch we are made conscious of bodies around us which resist compression, and may, therefore, be said to occupy space. Such bodies are said to be *material substances* or made of *matter*.

Every object that we know of possesses weight; that is, it requires some muscular effort to support it, or if it is hung on a spring the spring is stretched. What we call its weight is a force urging it toward the ground, and as the weight of two quarts of water is twice that of one quart we are led to think of the weight of a body as a proper measure of the quantity of matter which it contains.

But besides weight all bodies have inertia; that is, to produce a definite change per second in the motion of a body a certain force is required.

If a given body is isolated from other portions of matter, it may be heated or cooled or bent or twisted or compressed into small volume or allowed to expand into a large one, but in all these changes its weight and its inertia remain unchanged.

It will be seen later that if the body is taken from one place on the earth to another its *weight* also may change, so that **the only general property of a given portion of matter that cannot be changed is its inertia.**

It is this property, therefore, by which quantities of matter are defined, and two bodies which have equal inertias are said to have equal *masses* or to contain equal quantities of matter.

The actual comparison of two masses, however, is usually made by weighing, since under the ordinary circumstances of weighing, bodies which have equal weights have equal inertias.

7. Conservation of Matter.—The mass of a given portion of matter as measured by its inertia cannot be changed by any process known to man. Not only may a piece of wood be bent and twisted or compressed without changing its mass, but it may be burned in the fire, and chemistry shows that if the ashes and vapors and gases that have come from it are collected and separated from the gases of the air with which they may have united, it will be found that the united mass of the ash and the gases and vapors is the same as the mass of the original piece of wood.

This principle is known as the *conservation of matter*, and is established by innumerable experiments, both physical and chemical.

8. States of Matter.—Different kinds of matter differ greatly in the power of preserving their shape. Some, such as steel or copper, offer very great resistance to any attempt to change their forms. Such bodies are said to be *rigid* or *solid* bodies. Others, like water or air, have no permanent shape, but flow under the action of the weakest forces and take the shapes of the vessels containing them; they are called *fluids*. There are no substances that are either perfectly rigid or that are perfect fluids, for the most rigid bodies may be distorted, and those substances that flow most freely offer some resistance to change of form.

In some cases it is difficult to say whether a substance is to be regarded as solid or fluid.

Fluids are again divided into *liquids* and *gases*. *Liquids* are those fluids that can have a free surface and do not change much in volume under great changes in pressure. A mass of liquid has a nearly definite bulk though no permanent shape. Water is an example of a liquid.

Gases, on the other hand, are fluids that do not have a free surface, but completely fill the containing vessel, however much it may be enlarged.

A mass of gas may be regarded as having neither permanent shape nor size, since both of these are entirely determined by the vessel which contains it. Air is a familiar example of a gas.

UNITS AND MEASUREMENTS

9. Measurements.—The exact measurement of all the quantities involved in any phenomenon is a very important part of its study. It is largely owing to the recognition of this that such great advances have been made in physics during the last two hundred years.

Every measurement is essentially a comparison. A quantity to be measured is compared with another quantity of the same kind called the *unit.* Thus to measure a length it is necessary to find how many times the unit of length is contained in the given length.

The unit must be of the same nature as the quantity which is to be measured, since only like things can be compared. There must, therefore, be as many different kinds of units as there are kinds of quantities to be measured.

10. Absolute Measurements.—Each of the units employed might be arbitrarily chosen without reference to any other; the inch might be taken as the unit of length, the square foot as the unit of surface, and the quart as the unit of volume; but such a practice would lead to endless complications, especially when several different units are used in the same calculation, for it would be necessary in such a case to keep constantly in mind the number of square inches in a square foot, the number of cubic inches in a quart, etc. It is far simpler after choosing the inch as the unit of length to take the square inch as the unit of surface and the cubic inch as that of volume. The same principle applies in the case of all other units; none should be chosen arbitrarily which can be directly derived from those which have been previously selected.

A system such as this in which there are a few arbitrarily chosen fundamental units, between which no known connection exists and from which all other units are derived without introducing any new arbitrary factors, is known as an *absolute* system of units.

11. Fundamental Units.—All the phenomena of nature are manifested to us in *time* and in *space,* through the agency of *matter*. It is natural, then, that the fundamental units adopted as the basis of the system of measurement used in physics, should be the units of **time, length,** and **mass.** These are also convenient units, for lengths, times, and masses may be compared with great ease and precision, and all units that relate only to mass, motion and force or that depend on these by definition may be derived directly from them.

Physicists usually employ what is called the **centimeter-gram-second** (C. G. S.) system of absolute units in which the centimeter, gram, and second are taken as the units of length, mass, and time, respectively.

This system has the advantage of being in use by physicists all over the world, and therefore results expressed in its units are intelligible everywhere. But an absolute system might be based on any three units of length, mass, and time whatever. Thus a **foot-pound-second** system is used extensively in English-speaking countries.

12. Unit of Length.—The unit of length in the C. G. S. system of absolute measurement is the **centimeter,** or one-hundredth part of a meter. The meter is the distance between the ends of a bar of platinum which is kept in Paris and known as the *Mètre des Archives,* the bar being measured when at the temperature of melting ice. This bar was constructed by Borda for the French Government, and was adopted by them in 1799 with the view to its becoming a universal standard of length; it was intended to be exactly one ten-millionth part of the distance from the equator to the pole measured along a meridian on the earth.

It is now known that the earth's quadrant is about 10,000,856 meters in length, but as distances can be more easily and accurately compared with the length of the bar at Paris than with the length of the earth's quadrant, the former still continues to be the standard of length.

The English standard of length from which the foot and inch are determined is the standard yard, which is the "distance between the centers of the transverse lines in the two gold plugs in the bronze bar deposited in the office of the Exchequer" measured at the temperature of 62°F. This standard yard represents about the average length of the early yard measures that were in use, which were probably adopted as being half the distance which a man can stretch with his arms.

1 yard = 91.43835 cm.
1 foot = 30.47945 cm.

13. Unit of Mass.—The unit of mass in the C. G. S. system is the **gram,** or one-thousandth part of the standard kilogram, which is a mass of platinum kept at Paris and known as the *Kilogramme des Archives.* The standard kilogram was intended to represent the exact mass of a cubic decimeter of distilled water at its greatest density or at the temperature 4°C.

The gram is, therefore, equal to the mass of a cubic centimeter of pure water at 4°C. This relation between the cubic centimeter and the gram is exceedingly convenient, for it enables us to determine the volume of an irregular vessel from the weight of water which it can contain. But it is not a direct relation like that between the unit of length and unit of volume. Aside from convenience, there is no reason why a cubic centimeter of copper or mercury or of anything else might not have been taken as the unit of mass.

Since two masses may be compared with a far higher degree of accuracy than that with which the weight of a cubic centimeter of water can be determined, the **Kilogramme des Archives is the real standard on which all metric weights are based.**

14. Unit of Time.—**Intervals of time are always compared by the motions of bodies.** Two intervals of time are *defined* as equal when a body, moving under exactly the same circumstances in both cases, moves as far in the one time as in the other. The heavenly bodies have in their motions always furnished measures of time. One of the simplest natural units of time is the period of rotation of the earth, which is the interval of time between two succesive meridian passages of the same star. This is known as the *sidereal* day, and time reckoned in this way is called sidereal time. By considering the possible effect of tidal friction in retarding the earth's motion, Adams concludes that the period of rotation of the earth has not changed by more than one-thirtieth of a second in 3000 years.

The ordinary day is determined not by the rising and setting of the stars, but by the motion of the sun. When the sun is on the meridian it is said to be *solar* or *apparent* noon. The interval of time between two successive apparent noons is called the apparent or solar day. It is this time which is indicated by the sun dial. By means of clocks, which are machines constructed to run with great uniformity, one solar day may be compared with another, and it is thus found that they are not of equal length. The average length of the solar days in a year is known as the *mean solar day.*

The ordinary standard time used in everyday life is mean solar time.

The unit of time in the C. G. S. system is the mean solar second or the 86400th part of a mean solar day.