

to \$4 for every man, woman, and child. To say that 10 per cent of the light generated is wasted through misuse and ignorance is certainly a conservative estimate; this gives \$36,000,000 as the total amount of

loss from this source, or an average of 40 cents per capita for the entire population of this country. Aside from candles and kerosene oil, the waste is probably nearer twice this amount. If all items could be in-

cluded which pertain to the lighting industry, it appears likely that the grand total of expenditure per year would reach half a billion dollars. A portion of this, however, is in the line of permanent investment.

# G A S E S      A N D      V A P O R S.

## A SIMPLE STATEMENT OF THEIR PHENOMENA.

BY PROF. O. N. WITT.

At one time the name of vapors was restricted to the emanations which rose from volatile liquids on the application of heat, and could be condensed to the liquid form by cooling, and the name of gases to substances which were in the gaseous state at ordinary atmospheric temperatures and which resisted all attempts at condensation. At a later period, after Thilonier and others had shown that many gases could be liquefied by cold and pressure combined, a distinction was made between coercible and non-coercible gases. It was then demonstrated by Andrews, whose researches and deductions have been completely confirmed by more recent experiments, that non-coercible gases do not exist and that it must be possible to liquefy any gas if a sufficiently high pressure and low temperature can be obtained. This law apparently annihilated the distinction between gases and vapors.

But the distinction remained in popular speech and its propriety is now again conceded by science. The distinction which is now recognized, however, is purely one of physical condition, not one of material substance. In other words, the same substance may present itself as a gas or as a vapor.

Guy-Lussac's law of the expansion of gases is expressed by the equation  $V = V_0 (1 + aT)$ , where  $V$  and  $V_0$  denote the volumes occupied by a given mass of a gas at  $T$  degrees and at 0 degrees Centigrade (the pressure being the same in both cases) and  $a$  is the coefficient of expansion. This law is obeyed almost exactly by every gas so long as its temperature is much higher than the temperature at which it liquefies (at the pressure employed in the experiment), and for every gas under these conditions the coefficient of expansion is nearly the same and equal approximately to  $1/273$ . Hence for all gases under these conditions the equation

may be written  $V = V_0 (1 + \frac{T}{273})$ . If we suppose the

law to hold true down to the temperature of liquefaction, where the volume is reduced very nearly to zero,

we find  $1 + \frac{T}{273}$  nearly equal to zero or  $T$  nearly equal

to  $-273$  deg. C. For this and other reasons a temperature of approximately  $-273$  deg. C. is called the absolute zero, and on the assumption made above the liquefying points of all gases should be very near this temperature.

But if any gas is gradually cooled, a point is reached below which the contraction becomes perceptibly greater than  $1/273$  for each degree of cooling and continues to increase as the temperature sinks. If the increased coefficients of expansion (or contraction) thus indicated are introduced into the equation, we shall have  $V = 0$  at a temperature considerably above  $-273$  deg. C. And as the rapidity of increase of the coefficient and the point at which it becomes perceptible vary with different gases it is evident that the temperatures of liquefaction (under the same assumed pressure) must be different.

Of course, the point at which this phenomenon—the increase in the rate of expansion—commences cannot be determined with great precision, but it is obvious that this point marks the boundary between the gaseous and vaporous states.

An "ideal gas," to use a term of recent introduction, is characterized by strict obedience to Guy-Lussac's law of equal dilatation and to the law of Mariotte (or Boyle), according to which the volume of a given mass of gas varies inversely as the pressure of the temperature remains unchanged. A vapor obeys neither of these laws with strictness.

Very few substances are ideal gases even at the mean atmospheric temperature of 15 deg. C. (59 deg. F.). At this temperature hydrogen and helium are unquestionably ideal gases, but oxygen and nitrogen have probably reached the lower limit of the ideal gaseous state, while chlorine, carbon dioxide, sulphur dioxide and most other gases show so marked a divergence from that state that they must, in strictness, be classed as vapors.

At one or another higher temperature, however, every vapor acquires the character of an ideal gas and, at all still higher temperatures below the point of chemical dissociation, the substance strictly obeys

the laws of Gay-Lussac and Mariotte, and also the law of Avogadro, which expresses the fact that equal volumes of all gases at the same temperature and pressure contain equal numbers of molecules.

The transformation of gases into vapors at temperatures near their points of liquefaction is obviously a consequence of the essential nature of matter. We are ignorant of its mechanism and special causes, but they may, perhaps, be roughly sketched as follows: The molecules of a gas are pictured as perfectly elastic bodies which move, in virtue of their inherent energy, in straight lines, until they are deflected by impact against each other or the walls of the containing vessel. The conditions are similar to those of a great number of balls rolling in all directions on a billiard table, except that the motions of the molecules are not confined to one plane. Sir William Crookes, the Nestor of molecular physics, has compared the gas molecules to an imprisoned swarm of bees. If we imagine the bees to be untiring and elastic, so that they rebound after collision, the image is a fairly complete one. If the vessel is enlarged the bees will distribute themselves pretty uniformly throughout the larger space and will collide less frequently than before. If the space is contracted, the collisions will become more frequent. Now let us suppose that the bees, like real bees, lose energy and become fatigued. In default of other support, they cling to each other after collision, and the uniformity of distribution and the strict obedience to the laws of elasticity are destroyed. Soon all the bees cling together in one compact mass which falls to the floor of the prison. Here we have illustrations of the transformation of a gas into a vapor and the condensation of the vapor to a liquid. Another illustration is afforded by billiard balls covered with an adhesive substance which prevents them from rebounding after collision.

These illustrations suggest that the form of energy which is manifested in cohesion is peculiar to certain states of matter. It is not present in an ideal gas, but makes its appearance at the temperature below which the gas becomes a vapor. Gravitation between large masses, cohesion between molecules, and chemical affinity between atoms are only different forms of the universal force of attraction.

We know nothing of the atomistic state of matter, in which the atoms are not combined to form molecules. This state appears to be unattainable by human means, and since the development of the electronic theory it can hardly be even pictured in the form to which we had been accustomed. A molecular state of matter, in which the molecules exhibit no tendency to adhere to each other, is the state of an ideal gas. When cohesion commences and the molecules "coagulate," so to speak, the gas begins to be a vapor, and when the process of coagulation has been completed, the substance is a liquid or a solid. Of the molecular structure of liquids and solids we know nothing whatever.—Prometheus.

### LIFE OF A RADIO-ACTIVE ELEMENT.\*

By A. T. CAMERON.

A TYPICAL radioactive element gives rise continually to a radioactive product, together with one or more kinds of rays; radium gives rise to its emanation, and to  $\alpha$  rays. In addition, heat in comparatively large quantity is continually liberated.

This continuous production of both energy and matter is explained by Rutherford by the assumption that atoms of the parent element are continually being broken down, or disintegrated, into simpler atoms, the heat and rays being the difference in energy-content in the two atomic systems. When gun cotton is exploded a complex molecule is broken up into simpler ones, heat and light being also emitted. The two cases are parallel, the one being atomic, the other molecular.

It is found that the emanations, and many other active products, lose their activity almost completely in a measurable time. From studies of the rate at which the activity is lost, the conclusion is reached that in any one time a certain fixed proportion of the total number of atoms present spontaneously disintegrates. An actual illustration will make this clearer.

The activity of any fixed quantity of radium emanation falls to half the initial value in approximately four days. In the second four days it falls to half of this second value, i. e., one quarter of the original. We therefore suppose that the emanation has decomposed to a corresponding extent. In the unit of time chosen, four days, the same quantity, one-half the amount at the beginning of that period, always disappears. Similarly in any other definite period of time a certain quantity, bearing a definite ratio to the original amount, will disappear. Again, at the end of eight days one quarter of the whole amount remains; at the end of twelve days, one-eighth; of sixteen days, one-sixteenth. But at the end of infinite time there will always remain some quantity, however small. Similarly, in all cases of active matter some remains undisintegrated after infinite time; the radio-active elements have an *infinite life*. Though they may have *died* for all practical purposes at the end of some measurable time, an unmeasurable but definite amount remains. However, we can always find when half a given quantity of active substance has disappeared. And it is this period which is termed the *half-life period* of such substances. It varies from four seconds in the case of actinium emanation to millions of years in the case of uranium.

Another term constantly used is the *average life* of a substance. It can be conveniently illustrated by a human parallel. A church filled with people on any fixed date contains a fair assortment of men, women, and children of all ages. If we know the total number of years each person will live after leaving that church we can calculate the *average life* of the congregation, counting from the definite time fixed by that church attendance. This is quite different from the *average life* of some number of persons from the time of birth of each, which is the basis of the data employed to calculate insurance rates.

The *average life* of a radio-active element at any definite time corresponds to the first of these illustrations. If we take a definite quantity of radium salt, then the atoms of radium it contains are of all ages. If they have just previously been separated from their uranium ore some may have been born only a few weeks previously, others have existed thousands of years, just as the church congregation may include infants and old men of ninety. Of the radium atoms a certain number will *expire* in a definite time, just as in so many years a number of the worshipers will have died. And we can calculate the average life of the congregation of atoms with as much certainty as that of people.

The application of the second kind of *average life* to radio-active substances was recently worked out in some detail by Sir William Ramsay as a lecture illustration. Though it has just been stated that the life of a radio-active atom is infinite, yet infinity is only a relative term; in this connection it only means a longer time than we can measure. It is extremely probable that just as the human life is measurable and definite, so is, let us say, the life of an atom of radium. One may go further. For there is much more regularity in the life of this dead matter; the life of human beings is variable, dependent on "all the ills that flesh is heir to," microbes, the bearers of disease, and accidents, the ills of fortune. We have no ground to suppose that the life of a radio-active atom varies from any similar cause. For example, the rate of decay—the death rate—of radium emanation is unaltered within the limits of measurement between the temperatures of  $-180$  deg. and  $+1,600$  deg. C. (90 to 1,870 deg. in the absolute scale), the extremes at which, so far, it has been experimentally tested. If this tremendous difference of temperature does not hasten the decay of a single atom of emanation we can at least postulate that its life is not easily influenced by external causes. So far experimental work has shown that we cannot hasten or retard the death of a radio-active atom; consequently we cannot alter its life. For its birth is but the death of its parent atom, to which the preceding statement likewise applies. And we are justified in stating that the average life of a radio-active atom, as used in the second sense above, is in all probability the actual life of that atom.

\* Science Progress.