Laws of Matter Up-to-Date

Compiled by HELEN M. DAVIS, *Editor of* CHEMISTRY

1. A single ATOM is the tiniest particle of any chemical element that can exist by itself and retain the qualities that mark it as that element.

2. All material things in the universe known to our senses are composed of one or more CHEMICAL ELEMENTS.

3. Substances composed of more than one element are known as COMPOUNDS. Atoms of elements are held together in compounds by electrical forces in the outer parts of their structure.

4. The smallest unit of a compound, usually composed of two or more atoms, is known as a MOLECULE.

5. There used to be 92 chemical elements, from hydrogen ($_1H^1$) the lightest, to uranium ($_{92}U^{238}$), the heaviest. There are now two new elements, NEPTUNIUM ($_{93}Np^{239}$) and PLUTONIUM ($_{94}Pu^{239}$).

6. When elements are represented, as above, by their chemical SYMBOLS, the subscript number is the atomic number. This is different for each element. The superscript number represents the atomic weight.

7. One of the qualities characteristic of matter is weight or mass. ATOMIC WEIGHT is expressed on a relative scale, as compared with the weight of hydrogen which is taken as one.

8. ATOMIC NUMBER is the measure of the electric charge on the nucleus of the atom. Atomic weight is the measure of the atom's mass.

9. Different samples of the same element, when tested by chemists, are sometimes found to have different atomic weights. Lead which occurs with radium, for example, has a different atomic weight from ordinary lead.

10. In all other ways the two kinds of lead are chemical twins, exactly alike except for weight. Elements which differ in weight only are called ISOTOPES.

11. Uranium has several isotopes. The usual kind, whose atomic weight is 238, was used to produce the two new elements. U-235 was used to make the ATOMIC BOMB.

12. Each of the new elements, neptunium and plutonium, has two isotopes whose atomic weights are 238 and 239.

13. Different elements, quite distinct in chemical behavior, may have the same atomic weight. We have $_{92}$U-238, $_{93}$Np-238 and $_{94}$Pu-238, all with different properties. Such elements are now called ISOBARS.

14. All atoms are composed of standard interchangeable parts. These are PROTONS, NEUTRONS and ELECTRONS.

15. Protons and neutrons make up the NUCLEUS of the atom. The structure of the atom is much like that of the solar system. The nucleus corresponds to the sun at the center. The planets are electrons.

16. The proton and the neutron each have a mass about equal to that of a hydrogen atom, which is 1 on the chemist's scale. Each is about 1800 times heavier than the electron.

17. The ELECTRONS, light in weight and some distance away from the heart or nucleus of the atom, revolve around the nucleus much as planets revolve around the sun. They are held in their courses by electric attraction.

18. The proton has a POSITIVE charge of electricity, the electron has a NEGATIVE charge equal and opposite to the positive charge of the proton. The neutron has no charge at all.

19. The difference in chemical properties of the elements is caused by difference in the number of protons in the nucleus. This is the ATOMIC NUMBER.

20. Atomic weight is the SUM of the weights of the protons and neutrons in the nucleus.

21. It is the NEUTRON which figures in the transmutations which give atomic power. Neptunium and plutonium were formed by bombarding uranium 238 with neutrons.

22. Neutrons can PENETRATE to the nucleus of heavy atoms when charged particles would be repelled by charges in the atom.

23. The HYDROGEN atom is believed to have just one proton as its nucleus, with one electron circling around it. Hydrogen's atomic weight and atomic number are each one.

24. Hydrogen has one isotope which is just like ordinary hydrogen except that it is twice as heavy. It is known as "heavy hydrogen" and sometimes as DEUTERIUM. Its compound with oxygen is called "heavy water."

25. The nucleus of HEAVY HYDROGEN contains one proton and one neutron. The atomic number of heavy hydrogen is one, corresponding to one proton. The atomic weight is two, corresponding to the two heavy particles, proton and neutron.

26. HELIUM has two protons and two neutrons in its nucleus. The two protons correspond to helium's atomic number two. The combined weights of protons and neutrons in the nucleus give helium its atomic weight 4. Two electrons, held in their orbits by the two protons, revolve around the nucleus.

27. The VOLUME of an atom is determined by the orbits of its outermost revolving electrons. Only a small fraction of the size of an atom is actually occupied by the protons, neutrons and electrons, just as the space occupied by the sun, the earth and other planets is only a small part of our solar system.

28. In spite of all the unoccupied SPACE, an atom is quite IMPENETRABLE to other atoms and to larger bodies. The electrons revolve millions of times a second, and keep everything out of the space within quite as effectively as though they were everywhere at once.

29. The only things that can get inside an atom are smaller things, FRAGMENTS of other atoms, protons, neutrons or electrons. They must be shot with just the right speed. These fragments of atoms are observed as radiations given off by radio-active elements which are breaking up spontaneously.

30. RADIATION is wave motion, known to us as the electro-magnetic waves used for radio transmission, heat, light, X-rays and cosmic rays. Large numbers of extremely tiny particles in motion together act like waves.

31. Three types of radiation are given off by radio-active substances. ALPHA particles are high-speed nuclei of helium atoms. BETA particles are high-speed electrons. GAMMA rays are electro-magnetic radiations similar to X-rays and light.

32. Of these, only the gamma rays are properly called radiations, and even these act very much like particles because of their short wave-length. Such a "particle" or quantum of gamma radiation is called a PHOTON.

33. In general, the gamma rays are very penetrating, the alpha and beta rays less so. Even though the alpha and beta rays are not very penetrating, they have enormous SPEED.

34. The speed with which atom particles travel is the source of atomic energy. ENERGY is capacity to do work. It is work stored up for future use.

35. If you raise a weight to a height above the ground and suspend it there by some device, the WORK you put into raising it can be stored there indefinitely as POTENTIAL ENERGY. It will be there, ready, whenever you decide to release it.

36. The energy which a moving body has because it is in motion is called KINETIC ENERGY. The kinetic energy of any particle depends upon its mass and the square of its velocity. Energy is conserved by the moving particle until it strikes an object, then work is done.

37. All ENERGY is either potential or kinetic. Either one can be converted into the other. These two conversions are continually occurring.

38. Particles of atomic size have kinetic energy arising from several different kinds of MOTION. All atoms are constantly in motion.

39. If the atoms are so dispersed that the material constituting them is a GAS, that gas will exert pressure on all sides of the container that holds it. If the container is a balloon bag, the imprisoned gas can do work by lifting heavy weights into the air.

40. Atoms which compose an element that will combine readily with another element, as hydrogen or carbon will combine with oxygen, have unsymmetrical arrangements of the outer electrons in their systems. These unsymmetrical arrangements tend to set up a sort of strain, which causes CHEMICAL COMBINATION to take place when elements with suitable combining powers are brought together.

41. These unsymmetrical arrangements give rise to FORCES which result in kinetic energy. This energy appears, for example, when carbon and oxygen burn to carbon dioxide, giving off heat, or hydrogen and oxygen explode to form water, again giving off heat.

42. Chemicals combining to form stable compounds give off energy in the process. These are known as EXOTHERMIC REACTIONS. Combinations which absorb energy, forming unstable compounds, are known as ENDOTHERMIC REACTIONS. Explosives, for example, which are highly unstable, are formed by endothermic reactions.

43. Chemical forces, electricity and heat are all forms of energy. Potential and kinetic energy may be distinguished in each case.

44. These energies all arise from motion of the atom as a whole, or motion resulting from attractions and repulsions between the outer PLANETARY ELECTRONS of the atom's structure.

45. Energy resulting from motion of particles deep within the structure of the atom was unknown until the discovery of RADIOACTIVITY.

46. Radioactive elements undergo SPONTANEOUS breaking up of their atoms, giving off alpha and beta particles and gamma rays. Loss of these particles causes the radio-active elements to change into other elements.

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47. The energies shown in these TRANSFORMATIONS are thousands of times greater than the kinetic energies which the molecules of a gas have by reason of their motion when heated. They are thousands of times greater than the energy changes per atom in chemical reactions.

48. The property of matter that connects it with motion is INERTIA. Inertia is opposition to change of motion.

49. One conclusion that appeared early in the development of the theory of RELATIVITY was that the mass due to inertia of a moving body increases as its speed is increased.

50. This increase implied an equivalence between an increase in energy of motion of a body (kinetic energy) and an increase in its MASS.

51. It was for this reason that Einstein suggested that studies of radioactivity might show the EQUIVALENCE of mass and energy.

52. Einstein's statement is that the amount of energy, E, equivalent to a mass, m, is given by the equation $E=mc^2$ where c is the VELOCITY OF LIGHT.

53. From this equation, one kilogram (2.2 pounds) of matter, if converted ENTIRELY into energy, would give 25 billion kilowatt hours of energy. This is equal to the energy that would be generated by the total electric power industry in the United States (as of 1939) running for approximately two months.

54. Compare this fantastic figure with the 8.5 kilowatt hours of heat energy which may be produced by BURNING an equal amount of coal.

55. Until the atomic power research program, no instance was known of matter being converted into energy without more energy being used to produce the transformation than was released by it.

56. Two axioms of physics stated: (1) MATTER can be neither created nor destroyed; (2) ENERGY can be neither created nor destroyed. For all practical purposes they were true and separate principles until about 1940.

57. It is now known that they are, in fact, two phases of a single principle, for we have discovered that energy may sometimes be CONVERTED into matter and matter into energy.

58. Such conversion is observed in the phenomenon of nuclear FISSION of uranium, a process in which atomic nuclei split into fragments with the release of an enormous amount of energy.

59. The extreme size of the CONVERSION FACTOR explains why the equivalence of mass and energy is never observed in ordinary chemical combustion.

60. We now believe that the heat given off in such COMBUSTION has mass associated with it, but this mass is so small that it cannot be detected by the most sensitive balances available.

61. Transformation of matter into energy is an entirely different sort of phenomenon than the usual chemical transformations, where the matter is changed into a different form but its MASS persists.

62. From the standpoint of the Laws of the Conservation of Matter and of Energy alone, transformation of matter into energy results in the DESTRUCTION of matter and CREATION of energy.

63. The OPPOSITE transformation, which astronomers believe may be going on in some of the stars, amounts to the destruction of energy and the creation of matter.

64. It is difficult for us to imagine the reconciliation of two such different concepts as matter, with its characteristic mass or weight, and energy, which does not have this quality. We shall, perhaps, be forced to think of the stuff of the universe as some such combination of matter and energy as would be symbolized by the coined word "MATTERGY."

Science News Letter, October 6, 1945

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