pleteness. Mathematics and mathematicians live in them, and not infrequently lend themselves to genuine drama. The presentation of the whole is admirable. It is flowing and graceful and often characterized by a genuine and delightful humor. A feature which will be prized is the author's almost invariable practice of labelling all investigators and notable publications with their nationality and dates.

The publishers of the book are to be thanked for an attractive and legible volume. The author deserves recognition and high praise for a significant and timely work. Many the scientist who has come to realize, to his humility, that his vaunted work would in his absence have soon been accomplished by another. One may safely venture that no other would soon have written this book had Mr. Bell not done so.

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RADIOLOGIC PHYSICS

Radiologic Physics. By CHARLES WEYL, S. REID WARREN, JR., DALLETT B. O'NEILL. xvii + 459 pp. Springfield, Illinois: Charles C Thomas. 1941. $5.50.

THE book is divided into two parts: "(1) The theory and practice of electrical engineering as applied to radiological apparatus. (2) The theory and application of radiation physics with reference to x-ray diagnosis and x- and gamma-ray therapy." The first part includes chapters on electric circuits; electrical measuring instruments; transformers, generators, motors and distributing systems; electronics; electromedical apparatus. The second part deals with radiant energy; x-rays and matter; radioactivity and nuclear physics; measurement and control of x-rays and gamma rays; physical aspects of the use of x-rays for therapy, fluoroscopy and roentgenography.

The authors have adopted the analytical method in the presentation of the different subjects discussed, starting with the simplest concepts and gradually working towards the more complex ones. The book is intended as a text for students of radiology and as a reference book for the practicing radiologist and others. Exhaustive treatment of the great many topics discussed is not claimed by the authors. In general a judicious choice of the material included and details omitted has been made. There are some original and ingenious explanations of the operation of apparatus and the fundamental principles involved.

Bearing in mind that the book is intended primarily for radiologists, the desire on the part of the authors for pedantic accuracy and completeness is rather unfortunate. It conflicts with the requirement of simplicity and here and there leads to explanations which are too involved for the radiologist but too superficial for the physicist. An example of this may be found in the discussion of the standard free air ionization chamber on p. 291 *et seq.* Explanation of the operation of such items as the induction motor could have been left out to advantage. At times statements are qualified at length when a few words would have sufficed. As an illustration consider the statement on p. 320: "The quality of the γ-rays produced by a radioactive substance is independent of the amount of the substance that is used (whenever the number of atoms of radioactive material is large enough to produce γ-radiation that is continuous with time from the practical point of view)." The qualifying clause (which this reviewer has put in parenthesis) could very well have been omitted or at any rate replaced by the phrase "in radium therapy."

The disintegration constants of the uranium series on p. 262 are not the latest values, as given, for instance, in Rasetti's "Elements of Nuclear Physics." There are very few misprints. The type and paper, as well as the numerous illustrations, are excellent. The style and language are typical of the better engineering texts.

The authors are to be congratulated for the vast amount of time and effort spent in the preparation of this book, which, in spite of some shortcomings, successfully fills a gap in radiological literature. For the first time it is now possible to get a comprehensive view of the radiological armamentarium from a single volume. The book will be most useful particularly to the small, but rapidly increasing, group of physicists and engineers interested in radiologic physics.

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SPECIAL ARTICLES

CHEMISTRY OF ENERGETIC ATOMS PRODUCED BY NEUTRON CAPTURE

SOON after the discovery of the neutron production of artificial radioactivities by Fermi and his co-workers, Szilard and Chalmers[1] in England observed that a considerable part of the radioactive iodine (I^{128}) produced by irradiation of ethyl iodide with slow neutrons could be removed by the simple process of extracting with water or an aqueous solution of iodide ion. The explanation of this phenomenon was clear almost from the first. It was well known that throughout the periodic table nuclei differed in mass

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[1] L. Szilard and T. A. Chalmers, *Nature,* 134: 462, 1934.

by almost integral multiples of unity rather than 1.0089, the mass of the neutron. This meant that the process of neutron capture must liberate about 0.009 mass units of energy, *i.e.*, approximately 7 to 9 millions of electron volts. Since only 2 m.e.v. on the average are evolved in the beta radioactivity following the neutron capture, the remainder of the energy is expected to appear as one or more gamma rays. This was found to be the case, the average energy being between 3 and 6 m.e.v. and indicating the occasional emission of two gamma rays in sequence rather than one of higher energy. The relativity and quantum theories together with thermodynamics require that the emission of a photon of energy E involve a momentum E/c (c is the velocity of light). From the conservation of momentum this requires that the radioactive nucleus with energy $\frac{E^2}{2Mc^2}$ where M is the mass of the atom. For example, for I^{128} this means that the recoiling atom if free would have approximately 100 electron volts energy, amply sufficient to break any chemical bond, the strongest of which are about 5 e.v.

This process is known now to occur throughout the periodic table. It is more easily observed in cases where the ejected atoms after losing their excess energy by collision are unable to interchange places with the inactive atoms bound in the mother or target molecules which generally constitute the main part of the system. For example, if instead of ethyl iodide one uses hydrogen iodide, the separation of the active atoms is nearly impossible because of an extremely rapid thermal interchange of atoms between HI and I_2 or I or I^-. As a rough general rule one finds that thermal interchanges involving truly covalent bonds are slow. This is true for most organic molecules, of course, so one is able to study in these systems the reactions which occur while the ejected radioactive atoms are moving rapidly. Table I shows that these reactions are of considerable importance. It is a tabulation of the fractions of the induced radioactivities which are retained in organic molecules for various organic halides.

TABLE I

Compound	Retention (per cent.)
C_2H_5I	40
C_2H_5Br	75
C_6H_5I	65
C_6H_5Br	70
$C_2H_4Br_2$	31

Of course one wonders whether the high retentions may not be due to some unexpected failure of the bonds to rupture as a result of the recoil. This proves not to be the case, however, for either vaporization of the target substance or dilution of it with substances all of whose atoms are of widely different mass from that of the radioactive atom result in nearly zero retentions. Table II shows retentions obtained for solutions of CBr_4 in C_2H_5OH at various concentrations.

TABLE II

Mole per cent. CBr_4	(per cent.) Retention
100	60 ± 5
1.15	28 ± 5
0.74	13 ± 3
0.45	2 ± 2
0.064	0 ± 2

Table III shows the effect of vaporization on the retentions of two halides.

TABLE III

EFFECT OF VAPORIZATION

Compound	Retention in liquid, per cent.	Retention in gas, per cent.	Pressures (mm Hg)
C_2H_5Br	75	4.5 ± .4	390 mm + 370 mm air
$H_2CBr{-}CBrH_2$	31	6.9 ± .6	40 mm + 720 mm air

A further point of importance is that the processes of re-entry result principally in the formation of the mother molecule. For example, in the case of liquid brombenzene a fractional distillation, after extraction with a reducing aqueous solution, has shown that within 0.5 per cent. all the activity is present as monobrombenzene, rather than in any of the dibrombenzenes or other polybrominated molecules possible. Carrier substances were added to insure that small amounts of material would have separated at the ordinary temperatures.

These facts indicate that the re-entry process consists first of a collision between a rapidly moving radioactive atom or ion and the atom in a molecule of the target substance which has one unit smaller mass than that of the impinging particle and which by absorbing a neutron would become identical with it. Because these particles have nearly equal mass and the kinetic energy of the impinging atom is larger than the energy of the bond holding the struck atom to the molecule, there is a good chance that the kinetic energy will be largely transferred to the inactive atom and the radioactive atom will be left in the debris of the collision. For example, in the case of C_2H_5I the result would be that an ethyl radical and a radioactive iodine atom would be left near each other and free to combine to reform ethyl iodide but with the iodine atom radioactive now. Since it is most improbable that the collision will leave the active atom and the organic radical with exactly the right relative velocity to allow recombination, considerable rattling around in the cavity in the liquid is usually required before recombination occurs. For this reason re-entry in the gaseous state is greatly reduced, though a small amount should occur in the case of nearly perfect collisions.

The effect of interposing a foreign substance, such as C_2H_5OH in the case of CBr_4 none of whose atoms have masses near that of the active atom, obviously would be to slow the radioactive atom so that when it finally did make a collision with an atom of nearly its own mass it would have insufficient energy to rupture the bond in the "billiard ball" fashion described above. This of course results in nearly zero retention.

The principles outlined seem to be generally applicable. In review:

1. Retention of activity occurs mainly in the target substance.
2. Dilution with a solvent none of whose atoms are near the active atom in mass results in the limit in zero retention.
3. Retention in the gaseous state is much lower than in the liquid or solid state. The limiting retention at zero pressure is not necessarily zero, but may be a few per cent., depending on the molecule. Of course the reformed molecule is usually somewhat excited and may be able to take part in reactions which the normal molecule could not. These reactions may be used to liberate the active atom also. For example, Lu and Sugden[2] have shown that the addition of aniline to brombenzene reduces the retention very considerably, probably by the reaction

$$C_6H_5Br^* + C_6H_5NH_2 = Br^{\overset{*}{-}} + (C_6H_5)_2\overset{+}{N}H_2$$

resulting in the liberation of the active bromine atom.

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THE EFFECT OF HEAT ON CRYSTALS OF SERUM ALBUMIN; PRODUCTION OF CRYSTALS OF DENATURED PROTEIN

A study of the effects of heat on crystals of serum albumin has led to some curious and unexpected results. That heat denatures proteins is well known, and many investigations have been made on the heat denaturation of protein *solutions*. For a study of heat denaturation of proteins *in the crystalline state* horse serum albumin is a suitable protein because crystals of this protein do not tend to dissolve when the temperature rises, as crystals of egg albumin, for example, do. On the contrary, under certain conditions, warming a solution of horse serum albumin increases the rate of crystallization. If 0.5 ml of serum albumin solution (containing 50 mg of protein, previously crystallized, but not fractionated and subsequently dialyzed free of salt and then filtered) is added to 12 ml of a sodium sulfate-acetate solution (made by mixing 10 ml of 23 per cent. sodium sulfate with 1 ml of 2 M sodium acetate and 1 ml of 2 M acetic acid), crystallization begins in less than 5 minutes if the solution is warmed to 45° C., and within 15 minutes there appears a plentiful crop of large well-formed, needle-shaped crystals. At 25° crystallization proceeds much more slowly. These crystals dissolve at once if 12 ml of water are added. Heating the original solution of serum albumin in sodium sulfate-acetate to 60°, instead of 45°, causes a large flocculent precipitate of protein to appear almost at once. This precipitate is amorphous and, if heating at 60° is continued for 15 minutes, practically no protein dissolves when the suspension is subsequently cooled to room temperature and 12 ml of water are added. At 60° the amorphous protein precipitate obtained is obviously denatured.

At this point it seemed of interest to inquire what would happen to crystals of serum albumin if they were heated to 60° and still higher temperatures. For this purpose crystallization at 45° was allowed to proceed for several hours. The crystals were separated by centrifuging from the small amount of albumin still remaining in solution, and to the crystals was added the original volume of sodium sulfate-acetate mixture at 45°. In this medium the protein crystals were heated at various temperatures from 60° to 100° and finally in an autoclave at 115°, at each temperature for 15 minutes. At no temperature were the crystals destroyed. Even after heating at 115° the crystals seemed as perfectly formed as before heating.

The solubility of the heated albumin crystals was tested at room temperatures by adding to each heated preparation 2 volumes of water. The crystals heated at 60° dissolved in the course of five or ten minutes. Since heating a *solution* of serum albumin under the same conditions renders the albumin insoluble, it is clear that the protein in the crystal is not as easily denatured as is dissolved protein. If protein denaturation is an unfolding process, as there is good reason to believe,[1] then the increased stability of the protein in a crystal may be explained by supposing that the tendency of a molecule to unfold as the temperature is raised is opposed by the bolstering effect of neighboring molecules in the crystal.

Crystals of serum albumin heated at temperatures higher than 60° did not dissolve completely. A small percentage of those heated at 70° dissolved, but practically none of the crystals heated between 80° and 115° dissolved even after standing, with occasional stirring, for three days. These albumin crystals were not destroyed by being placed for several days in 1 N HCl or 95 per cent. alcohol. They dissolved at once, however, in a saturated urea solution. The insoluble serum albumin crystals are as insoluble as a heat-denatured, amorphous coagulum of serum albumin.

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[2] C. S. Lu and S. Sugden, *Jour. Chem. Soc.*, 1273, 1939.

[3] W. F. Libby, *Jour. Am. Chem. Soc.*, 62: 1930, 1940. This paper contains numerous other references of importance.

[1] A. E. Mirsky and L. Pauling, *Proc. Nat. Acad. Sci.*, 22: 439, 1936.