resulting from a proton-electron collision using the conservation of energy, but disregarding the conservation of momentum. Hughes and Jauncey stated in their letter that any annihilation process must satisfy the following conditions:

(1) Conservation of energy,
(2) Conservation of momentum,
(3) Conservation of charge,
(4) Reversibility of process considered,
(5) Velocities never to exceed that of light.

It was shown that with these conditions to be satisfied it is impossible for a photon to be formed by the mutual annihilation of a proton and an electron, no matter what their velocities or directions of motion may be. In the same letter it was also pointed out that, if we assume microscopic reversibility to hold, there is considerable difficulty in accounting for the reverse of Jeans' process, *viz.*, the disappearance of a photon and the appearance of a proton and an electron. As an alternative to Jeans' suggestion, it was shown that in a collision of two electrons and one proton (or two protons and one electron) giving rise to a photon and an electron (or proton) the above conditions are satisfied. Further comments by Hughes and Jauncey on this matter appeared in an article in the March 15, 1926 issue of the *Proceedings of the National Academy of Sciences* and in an abstract in the April, 1926 issue of the *Physical Review*.

Although our letter calling attention to the difficulties of the simple electron-proton annihilation hypothesis appeared within a few weeks of Jeans' announcement of the hypothesis in 1925, no attention whatever has been paid to it. Various writers discussing the annihilation theory of the origin of high-energy photons have continued to ignore the difficulty of the conservation of momentum until recently, and those who have recently paid attention to the point have completely ignored the fact that the question was raised and discussed rather fully eight years ago by us.

It is interesting to note that just recently Blackett and Occhialini have suggested that a high-energy photon on collision with the nucleus of an atom may give rise to an electron and a positron and a nucleus. This process can be made to satisfy all the conditions listed above.

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Washington University,
St. Louis Missouri,
December 27, 1933.

Indications of a Simple Rule Relating Nuclear Resonance Levels with Atomic Number

A study of the entry of alpha-particles into a nucleus which they disintegrate has shown that it occurs in general by two processes: first by penetration through the nuclear potential wall and, second by resonance with a "virtual" energy level inside. In an analysis of the experimental results on the minimum energies which will penetrate by the former process[1] I suggested that this energy, which is directly related to the height of the potential barrier, is a linear function of atomic number for light elements. It appears that a similar rule may hold for the resonance levels. Results are available for Be, B, N, F, Mg, Al[2] which are plotted in Fig. 1 together with the results on minimum

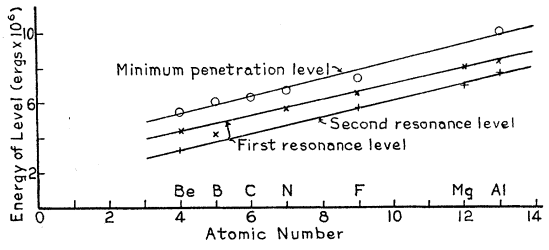

FIG. 1.

penetration level. It will be seen that for the two highest resonance levels the energy rises linearly with the atomic number and that the lines are parallel to the line relating minimum penetration level with the same quantity. It thus appears likely that *the energies of the resonance levels are a linear function of the atomic number*. The experimental accuracy is not as yet very high.

Both sodium and phosphorus disintegrate under alpha-particle bombardment with a release of energy. The protons so produced have therefore ranges sufficiently great to permit analysis into groups. Examination of these protons should show the existence of resonance levels at 7.4×10^6 and 6.6×10^6 ergs for sodium and 9.3×10^6 and 8.4×10^6 ergs for phosphorus.

An approximate explanation is suggested as follows: The light nuclei contain equal numbers of neutrons and protons. This can be used to explain the linear relation for the penetration level and it is found that if the attractive force between neutron and proton is represented by a potential of the form

$$V=ke^2/r^p,$$

where r is the distance between them, k is a constant and p is an unknown index, we have an expression

$$V=(2Ze^2/r)[1-(2k/r^{p-1})].$$

This is the equation representing the potential barrier around the nucleus. The potential V for a given r is proportional to Z, the atomic number. Now the resonance level is one for which the alpha-particle forms a standing wave within the potential barrier of the nucleus. If this

[1] E. Pollard, Phil. Mag. **16**, 1131 (1931).

[2] G. Bernadini, Zeits. f. Physik **85**, 555 (1933); J. Chadwick, Proc. Roy. Soc. **A142**, 5 (1933); E. Pollard, Proc. Roy. Soc. **A141**, 385 (1933); J. Chadwick and J. E. R. Constable, Proc. Roy. Soc. **A135**, 48 (1932); W. Bothe and H. Klarmann, Naturwiss. **35**, 639 (1933).

occurred at a constant radius for all light nuclei then the potential at which it did so would vary with the atomic number as found experimentally. For this to be so, the wave-length of the alpha-particle inside must be, approximately at least, a constant. If E is the potential energy of the alpha-particle inside and V is its kinetic energy of approach, its wave-length is $h/[2m(E+V)]^{\frac{1}{2}}$. Now an inspection of the change of the binding energy of light nuclei as an alpha-particle is added shows that the energy increases in equal increments, of the order of 10^{-7} ergs per alpha-particle.[3] Then, the wave-length of the alpha-particle will change slowly with V and so can be treated as constant for a first analysis, which means that the potential of the level of the standing wave is a linear function of the atomic number.

ERNEST POLLARD

Sloane Laboratory,
Yale University,
January 3, 1934.

[3] See Gamow, *Atomic Nuclei & Radio Activity*, p. 112.

Segregation of Polonium in a Bismuth Crystal

The magnetic properties of bismuth crystals and their variation with amount and kind of impurity are explained by Goetz and Focke[1] on the following assumptions: (1) That the abnormal ("crystal") diamagnetism of Bi is due to electrons which move in very large orbits $d \leqq 1\mu$ as suggested by Raman.[2] (2) That a secondary structure, characterized by equidistant π planes, postulated by Zwicky[3] for heteropolar crystals is also present in metals. (3) That those impurities which form limited solid solutions in bismuth enter only these π planes when the impurity is present in very small amounts. Two cases may be distinguished in Bi: (a) Metals of sub-group IV b which have one valency electron less than Bi (sub-group V b), such as Pb, Sn, Ge, enter a set of π planes which are steeply inclined to the (111) planes. (b) Metals of sub-group VI b which have one valency electron more than Bi, such as Te, Se, enter (111) π planes.

While these three assumptions explain the results very well, not one of them has been accepted as anything better than a questionable hypothesis. A very fortunate set of coincidences permits an excellent test of assumptions 2 and 3(b). The last member of the sub-group VI b is polonium, a radioactive element which disintegrates to lead with the emission of an α-particle of range 3.8 cm (air) or 13μ (Bi). According to Goetz[4] the distance between the (111) π planes of Bi is 0.4μ, thus if a crystal containing Po is cleaved on (111) and the Po is confined to (111) π planes, α-particles from some 30 planes should be able to emerge from the cleavage surface. After leaving the surface the α-particle would travel a distance in air dependent upon the depth of the layer from which it came. If then the number of α-particles per unit of time can be determined as a function of the distance from the point of observation to the crystal face, this number should be a discontinuous function. It should increase suddenly whenever the distance from point to crystal is decreased by the air equivalent of one Zwicky block.

To test this prediction a crystal infected with Po while molten, was cleaved parallel to the (111) planes. The cleavage face was then placed in a closed chamber 3.8 cm from a mica window (2.5 cm air equivalent). By varying the air pressure in the chamber the effective distance from the crystal to the counting device outside the window could be varied. One millimeter air equivalent corresponded to a change of pressure of 2 cm Hg. A Geiger counter placed before the window provided the means of counting the α-particles which came through. Counts were taken for pressure steps of one cm Hg and the curve given in Fig. 1

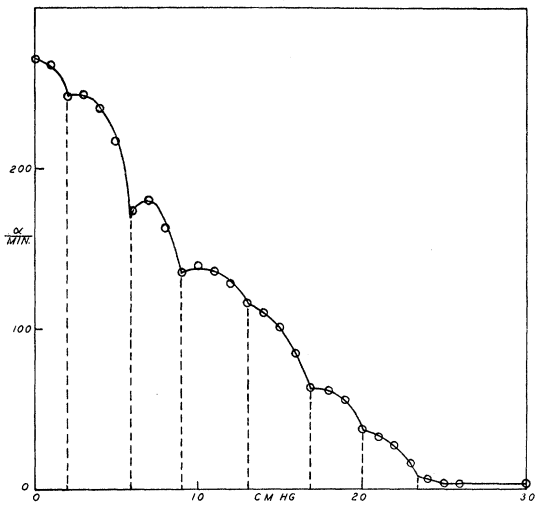

FIG. 1.

was obtained. The rounding of the steps may be explained in either or both of two ways; first, the α-particles straggle to some extent so that all do not have exactly the same range, and second, some Ra E may have been introduced into the bismuth along with the polonium. As Ra E is an isotope of Bi it would be free to occupy any point of the Bi lattice whence it could not depart at room temperature after disintegration to polonium. This uniformly distributed polonium would contribute a linear component to the observed number-distance curve.

In spite of these two difficulties the curve gives good evidence for the existence of relatively thin layers of polonium parallel to the (111) plane separated by a distance

[1] A. Goetz and A. B. Focke, Phys. Rev. **45**, 170 (1934).
[2] C. V. Raman, Nature **123**, 945; **124**, 412 (1929).
[3] F. Zwicky, Proc. Nat. Acad. Sci. **16**, 211 (1930).
[4] A. Goetz, Proc. Nat. Acad. Sci. **16**, 99 (1930).