The Hyperfine Structure and Nuclear Moment of Gold

The spectra of Au I and Au II were excited in a horizontal water-cooled hollow cathode tube and in a vertical liquid air-cooled tube. The tubes were operated with an applied voltage of 1000 and from 30 to 500 m.a. current. Reversal of the resonance lines of Au I took place down to 75 m.a. of current. The spectra were first examined in the higher orders of the 35 foot 30,000 lines per inch concave grating of the Institute and then examined with Fabry-Perot etalons of 5–25 mm spacing. For the region above 4500A evaporated silver films were employed, below 3000A aluminum-silicon, and aluminum for the intermediate region. Above 3500A the etalon was employed in the parallel beam of a Zeiss three-prism spectrograph and below 3500 the rings were projected on the slit of a Hilger E1 spectrograph with a long focal length achromat.

The splitting of the resonance lines is in good agreement with previous results of Ritschl.[1] The slight difference in splitting in the two lines 0.003 cm^{-1} can be attributed partially to the influence of the p level. A detailed intensity study of the two components in each of the lines using high contrast plates and stepped exposures as well as measurements with calibrated screens[2] permits a determination of $I=3/2$ with greater certainty.

Many of the lines such as 4607, 4488, 4439, 3029, 2883, and 2388, show four components. The levels involved have been investigated in other lines and in most cases can be relegated to a hyperfine structure term system if an I value of 3/2 is assumed which confirms Ritschl's previous assumption. The interval rule is better satisfied in a number of levels for an I value of 5/2 yet one would not expect it to be valid in view of the character of the coupling involved. Those levels of copper which show large isotope shifts have been investigated in gold. The relatively slight abundance of the weaker isotope and the apparent fine splitting involved does not permit any conclusion to be drawn in regard to its nuclear moment.

A detailed report of the above will be published in the near future.

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[1] Ritschl, Naturwiss. p. 690, 1931.
[2] Harrison, J.O.S.A. **19**, 267 (1929).

Stability of Beryllium

The existence of the alpha-radioactivity of beryllium reported by Langer and Raitt[1] having been made questionable by the work of Evans and Henderson[2] with the linear amplifier, a search for particle radiation of any kind, excepting neutrons possibly, with a sensitivity at least equal to those of the above-mentioned measurements for alpha-particles appeared to be of some interest.

This has been done by means of Geiger-Müller tube counters modified by using 40×40 mesh copper screen for the wall. The counter used had a diameter of 3.5 cm, a length of 17.5 cm, and a zero count of about 30 per minute when shielded from visible light, γ-rays, and cosmic rays by tar paper and an iron shield 1 ft. thick in nearly all directions. Air was used in the chamber at about 2 cm pressure and the operating voltages ranged between 1000 and 1300 volts. The amplifying mechanism was essentially that previously described.[3]

Samples were deposited uniformly over an area of 437 cm^2 by moistening soluble salts with alcohol and drying on the inner surface of a glass cylinder just large enough to slide over the screen counter. The effect per mole of KCl was repeatedly found to agree with 2780±200 counts per half minute. Since potassium is known to emit 27,500 per half minute this shows that about 10 percent of the emitted particles are counted in the case of the potassium β-rays.

Beryllium samples from three different commercial sources were used. All gave activities within 30 percent of a mean before purification. Because this mean value agreed with the Langer and Raitt value it was at first assumed that the activity was really due to Be. A screening test on one sample however showed that 16 percent passed through 0.08 mm of aluminum (13 cm air equivalent stopping power for α-particles) eliminating the possibility of the radiation being solely alpha in nature. Subsequent purification of one of the samples ($Be(NO_3)_2$ of Kahlbaum) gave a sample 0.034 mole of which deposited on the 437 cm^2 of glass surface as a mixture of BeO, $BeCl_2$, and $Be(NO_3)_2$ gave the results in Table I.

TABLE I.

Run	*Zero Count* Count	Time (½ min.)	Rate	*Zero Count Be Effect* Count	Time	Rate
No. 1	1696	101	16.8±0.3	2583	158	16.4±0.2
No. 2	2215	168	13.2±0.2	1468	110	13.3±0.2
	Effect = 0±0.24					
	Effect/mole = 0±7					

The probable errors given were found by the use of the Bateman formula ($r=0.67(\text{average rate})^{\frac{1}{2}}$) which is known to hold for this work as a result of somewhat extensive investigation during the last two years.

If one takes three times the probable error as an upper limit for the possible activity and assumes the $7.8\cdot10^{-5}$

[1] Langer and Raitt, Phys. Rev. **43**, 585 (1933).
[2] R. D. Evans and M. C. Henderson, Phys. Rev. **44**, 59 (1933).
[3] Libby, Phys. Rev. **42**, 440 (1932).

moles of Be salt per cm^2 of deposit to be sufficiently thin to make self-absorption negligible for β-particles certainly, and within a few percent for the weakest α-particles, the minimum possible apparent half-life for Be with respect to emission of single particles is $2 \cdot 10^{15}$ years. If one calculates on the basis of the emission of 2 particles at once as Langer and Raitt have done, the minimum life would be $4 \cdot 10^{15}$ years.

The sensitivity of the instrument for low-energy particles has been established previously by using aluminum screen instead of the copper and investigating the photoelectric effect. By means of a monochromator the photoelectric threshold of aluminum was found to be as low as 5000 Angstroms, the counting of the emitted photoelectrons being used to detect the effect. Also, calculation from the geometry of the counter, screen sample, etc., of the expected β-radiation effect due to potassium has always given the observed result within a few percent. It therefore seems probable that any radiation producing as much ionization as a photoelectron of a few volts energy should have been counted.

The $Be(NO_3)_2$ was purified by dissolving in water with $Pb(NO_3)_2$, saturating with H_2S, filtering, adding $Ba(NO_3)_2$, then $(NH_4)_2C_2O_4$ solution, filtering, titrating roughly with Na_2SO_4 solution to remove residual Ba^{++}, and evaporating to dryness.

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On the Nature of Cosmic-Ray Showers

The treatment of positive-negative electron pair formation as arising from the ionization of the completed negative energy electron shell around a positive nucleus, has occurred independently to several investigators.[1] This point of view seems to agree well with the experimental facts of the excess absorption of the 2.6 million volt radiation of Th C″ and the recent measurements of excess absorption by Gentner[2] for energies between 1 and 2.6 million.

However, this theory in its simple form is not in agreement with the state of affairs at very high primary energies, as it affords no explanation of shower formation and it requires the total absorption of the primaries (gamma-radiation or electrons) in pair formation, to vary much faster with the atomic number of the absorber, than the absorption of cosmic rays would seem to indicate. Shower formation cannot be a direct secondary effect of a single pair formation where an extraordinarily high probability of new pair formation by electrons of the original pair exists, for Anderson has obtained photographs of high energy electron tracks passing through thick pieces of Pb without shower formation, and suffering relatively small energy losses.

The results of Rossi[3] indicate that a secondary is produced which within a very short range in Pb, loses its energy principally by shower formation. It is here pointed out that a simple and natural explanation of shower formation follows from the assumption that Rossi's secondaries are very high energy protons or heavier nuclei. For, if a positive nucleus has a sufficiently high relative velocity to electrons at rest, so that this velocity is higher than that which electrons have after falling through 1 million volts, then the electrons at rest will be able to ionize the closed negative energy electron shell of the *oncoming* positive nucleus. In order to obtain this relative velocity for a proton, it is necessary for it to have more than 2000 million volts energy. A proton of less than this energy cannot produce showers. An electron with an energy somewhat over a million volts is assumed to have a high effective cross section of pair formation in collision with a nucleus. This assumption is subject to test in the cloud chamber by determining the frequency of pair formation in a thin metal sheet by electrons with energies between 1 and 2 million volts. The calculations of Furry and Carlson[4] are not applicable to this case. When the nuclei are stationary and the electron is moving, it will only form one pair, as it would lose the largest part of its energy in doing so. When the nucleus has the same velocity relative to electrons at rest, the nucleus loses a relatively small amount of energy in a pair formation, so that many pairs can be produced before the speed of the nucleus becomes too low. The density of electrons in Pb is so large, that these pairs can be formed in a very short length of its path. This would appear as a shower formation apparently originating from a small region.

The formation of very high energy positive nuclei from a penetrating primary could be either due to photoelectric ejection of parts of heavy nuclei by a very high energy gamma-radiation or more probably whole nuclei, or parts of them could be projected with high energy by neutrons of enormous energy constituting part of the primary radiation. Much more experimental evidence is needed to elucidate the exact nature of this primary absorption process. Secondary neutrons causing a tertiary positive nucleus projection would seem to explain the non-ionizing links of Blackett and Occhialini.

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[1] E.g., Beck, Zeits. f. Physik **83**, 498 (1933). Oppenheimer and Plesset, Phys. Rev. **44**, 53 (1933).

[2] Gentner, Comptes Rendus **197**, 403 (1933).

[3] Rossi, Nature **132**, 173 (1933).

[4] Furry and Carlson, Phys. Rev. **44**, 237 (1933).