Failure to Detect Radioactivity in Beryllium with the Linear Amplifier

We have attempted to confirm the pressure of radioactivity in beryllium, as observed in the ionization-chamber-electrometer measurements of Langer and Raitt,[1] by using a linear amplifier that will detect individual alpha-particles; but we have obtained negative results. In the present experiments an ionization chamber resembling that used by Wynn-Williams and others, 20 mm in diameter and 4.5 mm deep, with only a coarse wire-grid as first electrode, was connected to a Wynn-Williams linear amplifier. The output of the amplifier operated a loudspeaker, an oscilloscope, and a Thyratron counter. Standardization with polonium showed that the amplifier recorded each alpha-ray whose path in the chamber was 2 mm or greater in length. Qualitative tests showed the amplifier responsive to the alpha-particles emitted from the surface of a granite rock containing 10^{-12} g radium per g of rock.

A flat boss 20 mm in diameter was ground on a face of a lenticular block of beryllium, and this fresh beryllium surface was mounted 1 mm from the entrance to the ionization chamber. All alpha-particles emitted from the beryllium block with a range of 3 mm or greater should therefore have been recorded. Langer and Raitt postulate that each decaying atom of Be^9 emits 2 alpha-particles and a neutron and they ascribe a decay constant of 10^{-21} sec.$^{-1}$ and an alpha-particle range of 10 mm to beryllium. The Be alpha-particles should therefore have a range of about 5.2μ in Be, if the Bragg-Kleeman rule is assumed to hold. Thus there should escape from the Be boss used in our experiments some 2.9 alpha-particles per minute having a range greater than 3 mm of air, or 1.9 per minute having a range greater than 5.5 mm of air. The background count of the amplifier was about 0.5 per minute, hence less than one tenth of the expected beryllium activity could have been detected.

The experiments have been repeated four times during the past six weeks, always with negative results within the probable error. The last set of measurements will be given in some detail. Actually, the time of occurrence of each count was recorded, and analyses of these data, in the light of the Bateman criteria, demonstrated the true random character of the counting.

Table I shows the results of four measurements: first, unscreened beryllium; second, beryllium screened by aluminum foil of 1.5 cm air stopping power; third, unscreened beryllium; fourth, beryllium screened by aluminum foil of 3.5 cm air stopping power. The aluminum foil was fresh stock, and samples of it were tested in an ionization chamber and found to be free from radioactive contamination. The probable errors given were obtained from analysis of the data, using Peter's formula. These observations show the absence of alpha-ray emission from the beryllium block, well within the probable error, which is about 1/30 of the reported activity.

TABLE I.

	Run	Total counts	Duration	Counting rate
I	Be	24	45 min	0.53 ± 0.10
II	Be+1.5 cm Al	48	73	0.66 ± 0.10
III	Be	59	90	0.66 ± 0.09
IV	Be+3.5 cm Al	42	76	0.55 ± 0.09

Naturally, the results reported above do not prove that beryllium is wholly nonradioactive, but they do indicate that if beryllium is active it either emits very short (*ca.* 3 mm) alpha-particles, or has a decay constant which is much smaller than has been suggested by Langer and Raitt. Geological evidence, as Lord Rayleigh points out[2] is not in agreement with the second alternative, and mass defect considerations do not suggest a very short range alpha particle. The present experiments are therefore regarded as suggesting that beryllium is stable.

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[1] Langer and Raitt, Phys. Rev. **43**, 585 (1933).

[2] Lord Rayleigh, Nature **131**, 724 (1933).

Extension of Fowler's Theory of Photoelectric Sensitivity as a Function of Temperature

Fowler's highly successful application of the Fermi-Dirac statistics to photoelectric emission, in explaining the temperature variation of the apparent threshold, is valid for frequencies close to the threshold. The analysis starts with the following expression (in Fowler's notation) for the number of "available" electrons (with normal kinetic energies exceeding a particular value $\epsilon' = \chi_0 - h\nu$),

$$N_B = (4\pi kTm^2/h^3)\int_{\epsilon'}^{\infty} \log\,[1+\exp\,(\epsilon^* - \tfrac{1}{2}mu^2)/kT]du$$
$$= (2\pi kTm^2/h^3)(2kT/m)^{\frac{1}{2}}\int_0^{\infty} [y+(\chi_0 - h\nu)/kT]^{-\frac{1}{2}} \times \log\,\{1+\exp\,[-y+(h\nu-\chi)/kT]\}dy,$$

where

$$y = (\epsilon - \chi_0 + h\nu)/kT, \qquad \epsilon = \tfrac{1}{2}mu^2, \qquad \epsilon^* = \chi_0 - h\nu_0.$$

Fowler's ensuing treatment is restricted to cases where the frequency lies near the threshold by the assumption (a) that, before integration, y may be neglected in comparison with $(\chi_0 - h\nu)/kT$ in the denominator, and (b) that, in the final working expression, $\chi_0 - h\nu$ is approximately constant under these conditions.

It was thought desirable to investigate the extent to which these approximations are valid for frequencies removed from the threshold. A more general expression for the number of available electrons may be obtained somewhat more readily by integrating with respect to the normal velocity component, u, instead of the kinetic energy. Thus

$$N_B = (4\pi m^2 kT/h^3)\int_{u'}^{\infty} \log\,(1+Ae^{-au^2})du,$$

where

$$\tfrac{1}{2}mu'^2=\chi_0-h\nu,\qquad a=m/2kT,\qquad \log A(\text{Fermi})=\epsilon^*/kT.$$

If u^* is defined by $Ae^{-au^2}=1$, two cases arise as usual, namely $u'>u^*$ and $u'<u^*$, wherein the logarithm may be expanded in powers of Ae^{-au^2} and its reciprocal, respectively, with the result that probability integrals occur for which series approximations may be written at once. The results are:

$u'>u^*$ $(h\nu<h\nu_0)$:

$$N_B=[(2m)^{\frac{3}{2}}\pi k^2T^2/h^3\epsilon^{*\frac{1}{2}}]\{s_2(e^x-e^{2x}/4+e^{3x}/9-\cdots)-\tfrac{1}{2}\gamma s_3(e^x-e^{2x}/8+e^{3x}/27-\cdots)+\cdots\},\quad (1)$$

$u'<u^*$ $(h\nu>h\nu_0)$:

$$N_B=[(2m)^{\frac{3}{2}}\pi k^2T^2/h^3\epsilon^{*\frac{1}{2}}]\{s_1\chi^2/2+\pi^2/6-s_2(e^{-x}-e^{-2x}/4+\cdots)-\tfrac{1}{2}\gamma s_3(e^{-x}-e^{-2x}/8+\cdots)+\cdots\},\quad (2)$$

where

$$x=(\epsilon^*-\epsilon')kT=h(\nu-\nu_0)kT,$$
$$\gamma=kT/\epsilon^*=kT/(\chi_0-h\nu_0),$$
$$s_1=1+\delta/3+3\delta^2/16+\delta^3/8+\cdots,$$
$$s_2=1+\delta/2+3\delta^2/8+5\delta^3/16+\cdots,$$
$$s_3=1+3\delta/2+15\delta^2/8+35\delta^3/16+\cdots,\text{[1]}$$
$$\delta=(\epsilon^*-\epsilon')/\epsilon^*.$$

The two expressions are given to the first approximation in $\gamma(=kT/\epsilon^*)$ which is always small (of the order of 0.04 at most). Eqs. (1) and (2) differ from Fowler's (a) in the additional γ-term, and (b) in the introduction of the series in δ, which when multiplied by $1/(\chi_0-h\nu_0)^{\frac{1}{2}}$ replace the factor $1/(\chi_0-h\nu)^{\frac{1}{2}}$ and provide the desired correction for frequencies away from the threshold.

Using Eqs. (1) and (2) in further development after Fowler's method, on the assumption that the photoelectric current $I\propto N_B$:

$$I=A'T^2(\chi_0-h\nu_0)^{-\frac{1}{2}}f'(x),$$

where

$$f'(x)=s_2(e^x-e^{2x}/4+e^{3x}/9+\cdots)-\tfrac{1}{2}\gamma s_3(e^x-e^{2x}/8+e^{3x}/27-\cdots)+\cdots,\qquad x\leqq 0$$
$$=s_1x^2/2+\pi^2/6-s_2(e^{-x}-e^{-2x}/4+\cdots)-\tfrac{1}{2}\gamma s_3(e^{-x}-e^{-2x}/8+\cdots)+\cdots,\qquad x\geqq 0.$$
$$\log I/T^2=B'+F'(x),$$

where

$$F'(x)=\log f'(x),$$

and $B'=\log A'-\frac{1}{2}\log(\chi_0-h\nu_0)$, whose last term is strictly constant.

The function $F'(x)$ is seen to be dependent upon δ and γ as well as upon their ratio $x(=\delta/\gamma)$, and thus its universal character is gone to the extent of this higher approximation. When $\delta=0$ (at the threshold frequency, hence $x=0$) $F'(x)$ reduces to Fowler's $F(x)$ except for the added term in γ. In extreme cases (T large and ϵ^* small) this might amount to 2 percent of $f(x)$ or a difference, $F'-F=-0.01$. The deviations of $F'(x)$ from $F(x)$ depend upon the value of δ. Practical limitations on current measurement prevent δ from becoming more negative than -0.1. Such would be the case for Cs where $\lambda_0=6600\text{A}$, $\epsilon^*=1.53$ e.v. (assuming one free electron per atom) and incident light of $\lambda=7170\text{A}$. Then $F'-F$ would vary from -0.01 at $\delta=0$ to $\log(s_2+\frac{1}{2}\gamma s_3)=-0.016$ at $\delta=-0.1$.

On the short wave-length side of the threshold δ may become 0.2 for Ni illuminated with 2050A light, or 0.4 for Cs illuminated with 5000A light. In the case of Ni, $F'-F$ varies from -0.01 at $\delta=0$ to 0.03 at $\delta=0.2$, while for Cs, $F'-F$ varies from -0.01 to 0.07 at $\delta=0.4$, the upper limit being almost independent of temperature in each case. By examining Eqs. (1) and (2) it is seen that for values of x greater than 5, the γ term is negligible and $F'-F=\log s_1$, a function of δ only. So there is a slight change of shape in Fowler's theoretical curve to which experimental curves are shifted, depending upon the distance from the threshold.

If DuBridge's method[2] of plotting isochromatic instead of isothermal curves is used, for each curve there will be a constant δ and an almost constant difference $F'-F$ which produces a negligible change of shape and hence is absorbed in the arbitrary vertical shift. This method then introduces less error for frequencies far from the threshold.

If at any time the exact value of the proportionality constant between photoelectric current and the number of available electrons becomes of value, it will be given more accurately by this extension of Fowler's analysis.

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[1] These series converge for $\delta<1$.

[2] DuBridge, Phys. Rev. **39**, 108 (1932).

Nuclear Spin and Magnetic Moment of Sodium from Hyperfine Structure

Until recently attempts to determine the nuclear spin of sodium had led to inconsistent results. Recently Rabi and Cohen[1] from a Stern-Gerlach field deflection method and Joffe and Urey[2] from alternating intensities in band spectra have reported the nuclear spin of sodium to be 3/2. The writers have made measurements of the relative intensities of the hfs components of the sodium D lines which also yield 3/2 for the nuclear spin. In this research a liquid air cooled Schüler tube with argon as a foreign gas was used as a source. The hfs was resolved by means of a glass Fabry-Perot interferometer with spacers ranging

[1] Rabi and Cohen, Phys. Rev. **43**, 582 (1933).

[2] Joffe and Urey, Phys. Rev. **43**, 761 (1933).