The total integrated cross sections are 2.8 Mev-barns for tantalum and 3.0 Mev-barns for bismuth, with the $(\gamma, 2n)$ contributing approximately 15 percent in each case. The sum rule prediction that the integrated cross section be given by

$$\int_0^\infty \sigma dE = 0.060(NZ/A)(1+0.8x),$$

where x is the fraction of exchange force in the proton-neutron interaction, is in excellent accord with the results. The calculation of the fraction of exchange force, however, would require better techniques than the photon-difference method of obtaining cross sections from the yield data, especially as to any tail on the curves above 23 Mev, and also some determination of the importance of (γ, γ) processes. As can be seen, the shapes of the excitation functions of bismuth and tantalum are markedly different.

Work is continuing on other elements as well as on the detection of coincidences in the $(\gamma, 2n)$ process.

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Fourth-Order Vacuum Polarization

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WE have calculated the contribution from vacuum polarization to the fourth-order radiative correction to the motion of a slow electron in an external field.

Consider a single scattering of an electron in an electrodynamic potential varying in time and space as $\exp(iq_\mu x_\mu)$; we write q^2 for $(\mathbf{q}^2-q_t^2)$, and m for the electron mass. If $q^2 \ll m^2$, the radiative corrections to scattering can be expanded in powers of (q^2/m^2) and of the fine structure constant α. The lowest term, which is due to vacuum polarization, in this expansion is the well-known Uehling[1] term whose ratio to the zero-order scattering is

$$(1/15)(\alpha/\pi)(q^2/m^2). \quad (1)$$

The terms of order α^2 are the fourth-order radiative corrections. Various authors[2] have already discussed and evaluated all these terms, except for the contribution from vacuum polarization. The term in α^2 due to vacuum polarization comes from the three fourth-order diagrams shown in Fig. 1. To lowest order in q^2 these diagrams give a correction potential, whose ratio to the zero-order potential is of the form

$$K(\alpha/\pi)^2(q^2/m^2), \quad (2)$$

where K is a dimensionless constant to be determined.

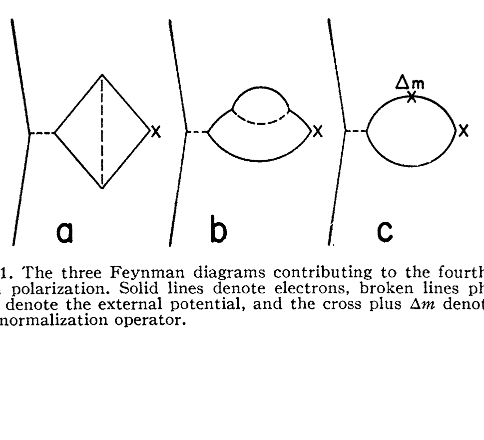

FIG. 1. The three Feynman diagrams contributing to the fourth-order vacuum polarization. Solid lines denote electrons, broken lines photons. Crosses denote the external potential, and the cross plus Δm denotes the mass renormalization operator.

The evaluation of the constant K was carried out along the lines of the Feynman formalism.[2-5] To carry out the mass-renormalization in an unambiguous way a regulation procedure[3,6] was used, involving "photons" of very large mass Λ. The calculations were arranged, making use of the principle of gauge invariance, so that charge renormalization and photon self-energy divergences were automatically excluded. The contributions to K from the three diagrams in Fig. 1 were evaluated separately. The calculations were tedious but very much simpler than those of other fourth-order terms,[2] because in this case the final expressions to be integrated were always rational functions with a single simple denominator. The underlying reason for this simplification is not clear to us. No transcendentals appear in the final results, which are

$$K_a = (1231/8100) + (1/30)\log(\Lambda^2/m^2), \quad (3a)$$
$$K_b = (23/450) - (2/15)\log(\Lambda^2/m^2), \quad (3b)$$
$$K_c = -(1/20) - (1/10)\log(\Lambda^2/m^2), \quad (3c)$$
$$K = K_a + K_b - K_c = 41/162. \quad (4)$$

The constant K is independent of the cutoff Λ.

The vacuum polarization terms have a nonzero expectation value for the $2S$-state of hydrogenic atoms, zero expectation value for the $2P$-state (to this order). They therefore contribute to the Lamb shift, the contribution of the fourth-order terms, Eq. (2), being -0.239 Mc/sec for hydrogen and deuterium, compared with -27.13 Mc/sec from the Uehling term, Eq. (1). All other fourth-order contributions to the Lamb shift have been calculated previously,[2] and also the corrections[7] to the second-order terms produced by the failure of the approximation $q^2 \ll m^2$. Including these contributions, and corrections due to nuclear mass, radius, and structure,[8] the theoretical values[9] for the Lamb shift are (1057.19 ± 0.16) Mc/sec for hydrogen and (1058.49 ± 0.16) Mc/sec for deuterium. These values are about half a megacycle smaller than the corresponding experimental values.[10]

We are indebted to Professor N. M. Kroll and Dr. J. Minkowski and Dr. S. Triebwasser for unpublished communications.

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Isomeric Levels in Pb^{201} and Pb^{202}

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SHORT period gamma-activities following proton bombardment of thallium targets have been studied using a sodium iodide scintillation spectrometer. Decay periods of 50 seconds and 5.6 seconds have been observed, and assignments have been made to isomeric levels of Pb^{201} and Pb^{202}, respectively. The γ-ray energies measured were 0.67, 0.42, and 0.25 Mev for the 50-second decay and 0.89 Mev for the 5.6-second decay. Channel analysis of the spectra was accomplished by brightening individual pulses with a circuit due to Watkins[1] and displaying on a triggered oscilloscope. Photographing the screen on moving film yielded permanent records which were later projected and analyzed to give the pulse-height distributions. The 0.510-Mev γ-ray of Sr^{85} was used as a convenient calibration line together with Co^{60} lines.

The 5.6-second period was measured using a method due to Breckon and Martin.[2] For the 50-second activity it was possible to carry out chemical separation of the active lead from the thallium target. This showed conclusively that the activity was in the lead of the precipitate and not in the thallium of the filtrate. Neither of the activities was observed following bombardments of mercury targets. Thresholds for production were compared with the threshold for production of 8-hour Pb^{201}, and this comparison supported the proposed assignments. Comparison of the energy of the 5.6-second γ-ray with the energy of a γ-ray found in polonium extracted from a bismuth target indicated that the α-decay of Po^{206} probably goes to the 5.6-second excited level of Pb^{202}.

Intensity of the 0.67-Mev line of the 50-second activity appeared to be about four times that of the two lower energy lines on the basis of comparisons of the areas under the photoelectric capture peaks. Although definite transition types cannot be specified, it is interesting to note that the energies 0.42 and 0.25 Mev are in line with the energy spacings of $i_{13/2}$ to $f_{5/2}$ and $f_{5/2}$ to $p_{1/2}$ levels for adjacent isomers of odd neutron number as plotted by Hill.[3] The type of transition giving rise to the intense 0.67-Mev line is particularly puzzling since a crossover transition $i_{13/2}$ to $p_{1/2}$ is ruled out as being of type $M6$. Further data are required before this point can be clarified.

In the course of this investigation the period of the known Pb^{207} metastable state was redetermined as 0.80 ± 0.02 second.

Indebtedness is expressed to Dr. J. S. Foster, Director of the Radiation Laboratory, to Dr. S. W. Breckon and Dr. A. L. Thompson, and to the National Research Council of Canada for two studentships.

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Heat Pulses in He II Below 1°K

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The fact that below 1°K the speed by which heat pulses travel in He II increases enormously[1] has generally been regarded as a confirmation of the Landau version of the two-fluid model.[2] According to that version the so-called normal fluid would essentially consist of rotons, the role of which would be taken over by phonons below 1°K.

In different laboratories it has been observed, however, that the width of the heat pulses increases greatly, and this might suggest that at the lowest temperatures one does not have to do with second sound proper but with the normal transmission of heat pulses in a medium of a certain specific heat and thermal conductivity. The formulas of Kronig and Thellung[3] might be appropriate to describe the transition to the phenomenon of second sound above 1°K. The magnitude of the speeds observed suggests that the mean free path of the phonons responsible for the thermal conductivity is determined by the width of the vessel.[4] The difference with Landau's picture would consist of his emphasis on the momentum of the phonons and of their large effective diameter for collisions.

Mr. H. C. Kramers in Leiden is preparing to investigate the expected influence of the length and the width of the vessel. The publication of the present letter was stimulated by a discussion with Dr. Pellam and Dr. De Klerk, who kindly showed me the recent results obtained at the Bureau of Standards.

Finally, it might be suggested that the increase of the second sound velocity[5] above 1°K upon dissolving He^3 also could be accompanied by an increase of damping and dispersion and so indicate an earlier transition to the very low temperature case.

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Mass Assignment and Gamma-Radiations of the Seven-Hour Molybdenum Isomer

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The 7-hr isomer activity in molybdenum produced by proton[1-3] and by deuteron irradiation of niobium,[2,4] by alpha-particle bombardment of zirconium,[2,5,6] and in very low yield by fast neutron irradiation[6] of enriched Mo^{94} is of interest in that its assignment to mass 93 cannot be easily reconciled with predictions from shell theory.

Some doubt concerning this mass assignment has persisted, for, unexpectedly, it has not been possible to prepare 7-hr Mo^{93} by deuteron bombardment[6] of enriched Mo^{92}, or by a (γ, n) reaction when enriched Mo^{94} was irradiated with 23-Mev γ-rays.[7] In addition, despite numerous attempts, we have been unable to produce any detectable amounts by irradiating molybdenum enriched to 92.1 percent in mass 92 with slow neutrons in the Oak Ridge graphite pile, nor has this period been observed as a daughter from intense sources of 2.75-hr Tc^{93} produced by a (d, n) reaction on Mo^{92}. Again, in recent bombardments of molybdenum with 20-Mev protons no 7-hr molybdenum whatever from the energetically possible (p, pn) reaction could be detected, although easily measurable quantities of the well-known 67-hr Mo^{99} were formed.

To make quite certain that the 7-hr activity was correctly assigned chemically, a molybdenum fraction was separated from niobium irradiated with 20-Mev protons and exhaustively purified. The decay of gamma-radiations from this purified source was accurately exponential for more than 60 hours and gave a half-life value of 6.95 ± 0.05 hours. Measurements of the γ-ray spectrum were also made using a (Tl+Na)I crystal scintillation counter spectrometer. Energies of 290, 690, and 1464 kev for the photoelectric peaks (Fig. 1) which decayed with a 7-hr half-life were estimated to within 3 percent by comparison with the 141-kev C^{144}, the 661-kev Cs^{137}, and the 1175-kev and 1332-kev Co^{60} γ-rays, respectively. These values appear to be in good agreement with recent magnetic lens spectrometer measurements of conversion and photoelectron energies,[8] except for the lowest energy transition. The observed relative intensities of the (unconverted) γ-rays were as 11.2:4:1, which, when compared with the detection efficiency ratios of 18.3:4.1:1 for 290-, 690-, and 1464-kev quanta, respectively, indicate the latter two γ-rays to be equally abundant, and the lowest energy gamma to have a total conversion coefficient of 0.6 ± 0.2. Measurements on a portion of the original proton-

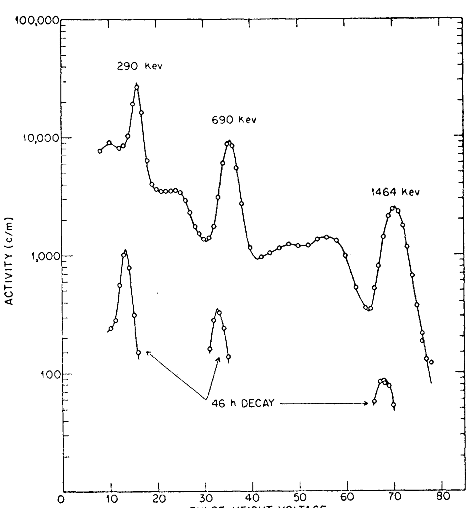

Fig. 1. Gamma-ray spectrum of 6.95-hr Mo^{93} (Tl+NaI scintillation counter spectrometer).