Appendix D

"Determination of the rest-mass energy of the electron...", Am J. Phys Vol 45 No 11, Nov. 1977

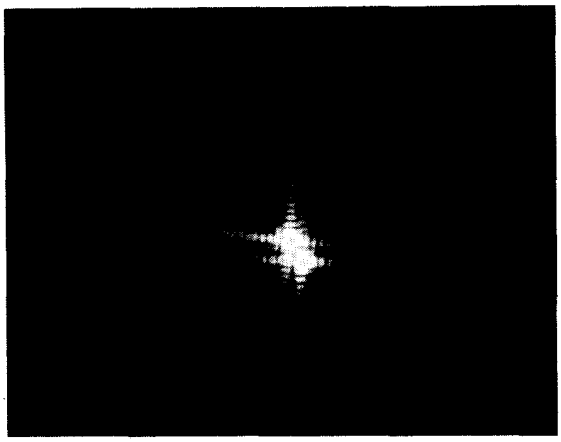

Fig. 1. The output of a misaligned double-beam interferometer illuminated through a square aperture.

this simple aligning technique. Such rotations cannot be tolerated in interferometric systems and may be troublesome also in other applications.

In noncoherent systems, rotational alignment is achieved by using some kind of reticle (i.e., cross hairs). Unfortunately, due to diffraction, a reticle does not solve the problem in a coherent system. We found it very useful to convert the whole laser beam into a "reticle." This can easily be done by inserting an aperture of some definite form in the beam in order to produce a diffraction pattern—the "reticle" of the desired form. For example, a circular aperture produces a set of concentric rings that are useful in accurate centering of the beam. In our laboratory[1] we used a square aperture in order to align an interferometric system with two laser beams exactly colinear and allowing no rotation between them. Figure 1 shows the output of the system with inaccurate alignment (a slight displacement of the beams was also introduced for clarity.

many cases this is adequate. However, when a larger number (over three) of reflections are involved they may introduce a rotation in the beam which is undetectable by

[1]J. Shamir, Appl. Opt. **15**, 120, (1976).

Determination of the rest-mass energy of the electron: a laboratory experiment

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The rest-mass energy of the electron is an important quantity in physics and it is desirable to have a laboratory experiment to determine it. This can be done by making use of the Compton scattering in which an incident photon of known energy shares energy and momentum with an electron at rest. It can be shown[1] that in a head-on collision with an incident photon of energy E_γ, the electron receives the maximum possible energy given by

$$T_{\max} = E_\gamma[1 + (m_0c^2/2E_\gamma)]^{-1} \quad (1)$$

and the back-scattered photon has the minimum possible energy given by

$$E'_\gamma = E_\gamma - T_{\max} = m_0c^2[2 + (m_0c^2/E_\gamma)]^{-1}, \quad (2)$$

where m_0 is the rest mass of the electron and c is the velocity of light. Thus, by experimentally determining either $T_{\max}$ or E'_γ for a known E_γ the electron rest-mass energy m_0c^2 can be determined.

This experiment can be done in any undergraduate laboratory which is equipped with a gamma-ray spectrometer consisting of a NaI($T1$) crystal coupled to a photomultiplier and a single- or multichannel analyzer to determine the pulse-height distribution due to monoenergetic gamma rays falling on the crystal. The photoelectric absorption of the incident photons lead to a peak called the photopeak whose maximum corresponds to the energy E_γ of the incident photons. The Compton scattered electrons have a continuous distribution of energy from zero to $T_{\max}$ and these lead to the so-called Compton distribution in the pulse-height spectrum. Because of the finite resolution of the crystal, the Compton distribution has at the higher energy end a rapidly falling part called the Compton edge. The pulse height corresponding to the midpoint of the Compton edge may be taken as corresponding to the electron energy $T_{\max}$. On the other hand, if the head-on collision takes place at the interface between the crystal and the glass envelope of the phototube, the electron would escape from the crystal and the back-scattered photon of energy E'_γ may undergo photoelectric absorption in the crystal. Such processes lead to a well-discernable peak called the back-scattered peak which is superposed on the continuous Compton distribution.[2] If, using a set of gamma sources of known energy, the spectrometer is calibrated so that the pulse height can be expressed in terms of energy, the pulse heights corresponding to the photopeak, the Compton edge, and the back-scattered peak can be directly expressed in terms of energy, and using Eqs. (1) and (2) the value of m_0c^2 can be determined.

We report the results we have obtained by using a NaI($T1$) crystal of 1-in. diam. and 1-in. height coupled to

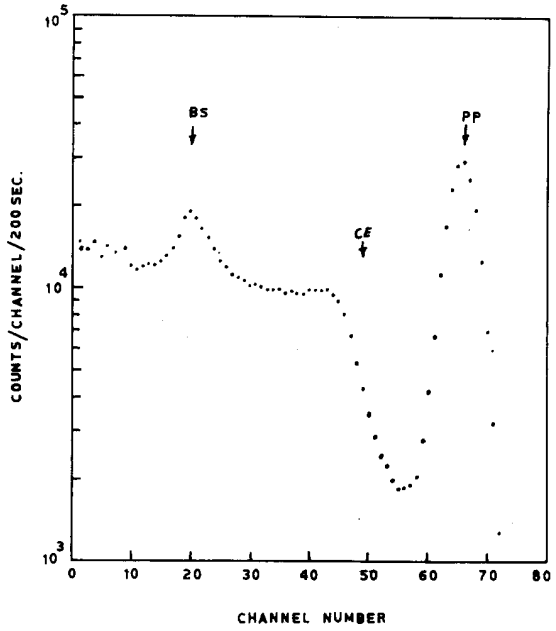

Fig. 1. A typical pulse-height distribution obtained with a ^{137}Cs source, where *BS*, *CE*, and *PP* indicate, respectively, back-scattered peak, the Compton edge, and the photopeak.

an RCA-6199 photomultiplier. The pulse-height distribution is obtained by using a multichannel analyzer. A typical pulse-height distribution is given in Fig. 1. The gamma sources used, their half-lives, the values of E_γ, T_{max}, and E'_γ are given in Table I. The sources are of 10 μCi. In column 6 we give the values of m_0c^2 obtained by using Eq. (1), and in column 7 the values obtained by using Eq. (2). The uncertainty in determining T_{max} and E'_γ from the observed pulse-height distribution is about $\pm 1/2$ channel, i.e., about ± 5 KeV. This leads to an error of about ± 20 KeV in the calculated rest-mass energy of the electron. The mean value of the rest-mass energy of the electron is found to be 516 ± 20 KeV which is close to the standard value of 511 KeV. Using the standard value of the velocity of light, the mass m_0 of the electron can be calculated. In our case it comes out to be $(9.20 \pm 0.35) \times 10^{-28}$ g comparable to the standard value of 9.108×10^{-28} g. Greater accuracy can be achieved by using a Ge(Li) detector, if available.

Table I. The values of the electron rest-mass energy (m_0c^2) calculated using the experimental values of the Compton edge (T_{max}) and the back-scattered peak (E'_γ) are given in columns 6 and 7, respectively, for the three gamma energies (E_γ) used. The error of ± 20 KeV corresponds to the uncertainty of $\pm 1/2$ channel (i.e., ± 5 KeV) in determining T_{max} and E'_γ from the pulse-height distributions. Mean value of $m_0c^2 = 516 \pm 20$ KeV.

Source	Halflife	E_γ KeV	T_{max} KeV	E'_γ KeV	m_0c^2 KeV	m_0c^2 KeV
^{137}Cs	30y	662	480	190	502	533
^{54}Mn	310d	840	640	200	525	525
^{65}Zn	245d	1114	910	210	499	517

We are grateful to the University Grants Commission for the financial assistance.

[1] R. D. Evans, *The Atomic Nucleus* (McGraw-Hill, New York, 1955), p. 672.

[2] J. H. Neiler and P. R. Bell, "The Scintillation Method," in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland, Amsterdam, 1965), p. 245.

Half-life of thorium-232: a laboratory experiment

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We report a simple laboratory experiment to estimate the half-life of ^{232}Th, which also familiarizes the students with the technique of absolute counting with a 4π geometry using a liquid scintillator.[1] The isotope has an abundance of 100% and its decay series is well known.[2] The longest lived product ^{228}Ra, has a half-life of 5.75 y. So, in any thorium sample which is more than about 35 y old, all the decay products would be nearly in secular equilibrium with thorium, leading to emission of six alpha particles in the energy range from 4 to 9 MeV and four beta particles belonging to beta spectra having endpoint energies from 0.012 to 2.25 MeV. In this experiment a known amount of thorium nitrate is dissolved in a liquid scintillator and a difference method is used to determine the counting rate due to alpha particles only. As there are six alpha emissions in the series, one-sixth of this counting rate gives the disintegration rate of thorium in the sample. From this, the half-life of thorium can be calculated. The experiment can be done in 3–4 h using a single or a multichannel analyzer, or even a scaler-discriminator setup.

A liquid scintillator solution is prepared by dissolving 25 mg of *p*-terphenyl in 5 cc of dioxane. Of this 2 cc is poured into a flat-bottomed Pyrex glass cell of 2 cm diam and 2 cm height and an exactly weighed quantity of 2 mg of anhydrous thorium nitrate, $Th(NO_3)_4 \cdot 4H_2O$, is dissolved in the solution. In our experiment, we have used a sample which was purchased by our department 20 y ago. The cell is mounted on an RCA 6199 photomultiplier and covered