$-[(rp)'/r]'_i$. The solutions are thus the same as (11), but with ω_r and n_i replaced by $\omega_A = m_i v/r_i$ and m_i, defined by

$$-[(rp)'/r]'_i = m_i^2 p_i/r_i^2. \quad (15)$$

Choice of the field shape

It has been shown that there must be a position of minimum electric field (i.e., $A'_0=0$, $A''_0>0$) for radial stability, and that the field must decrease with increasing distance from the axis for axial stability of the electrons. If the field in the region of the electron's orbit is of the form

$$H_z = H_0(t)(r_0/r)^n,$$

the vector potential is given by

$$A = \frac{H_0(t)}{2-n}\left[\frac{r_0^n}{r^{n-1}} + (1-n)\frac{r_0^2}{r}\right].$$

The second term in the bracket gives an electric field, but no magnetic field at the position of the orbit; it represents the effect of the strong central magnetic field required to satisfy the flux condition (2).

Evaluating (10) and (15) for this potential we find

$$n_i^2 = (1-n), \quad m_i^2 = n.$$

The conditions for radial and vertical focusing, $n_i^2>0$, $m_i^2>0$, thus demand $0<n<1$, as we have already seen.

An electron deflected from its instantaneous circle by a small angle scattering will execute oscillations of amplitude proportional to the transverse velocity imparted by the scattering divided by the initial frequency of oscillation. The ratio of radial to vertical amplitude will thus be

$$x/z = [n/(1-n)]^{\frac{1}{2}}.$$

Since in the Illinois accelerator the vertical clearance was smaller than the horizontal, it was desired to have vertical focusing stronger than horizontal focusing. The pole pieces were accordingly shaped to give a field with $n=\frac{2}{3}$.

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The Resonance Energy of the Thorium Capture Process

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IN a paper dealing with the capture cross section for thermal neutrons in thorium[1] it was pointed out that the pure capture process in thorium has a resonance character with a large contribution from thermal neutrons.[2] The following experiments were carried out in order to determine the resonance energy of this process.

As the neutron source available was only 100 mg Ra+Be, it was not possible to determine the resonance energy in the usual way, i.e., by measuring the absorption coefficient of boron for the resonance neutrons with thorium 233 as detector. We therefore made use of a less direct method by measuring the absorption in thorium for various neutron resonance groups picked out by suitable detectors. If there are found neutron groups having absorption coefficients whose ratio is not inversely proportional to the ratio of the respective velocities, one can expect that a resonance group of the thorium capture process is lying within the range of the energies under investigation.

Since the large contribution of thermal neutrons to the capture process in Th suggested that the resonance energy might be rather low, Au ($E_r=3.5$ ev),[3] In ($E_r=0.9$ ev)[4] and Rh, which has the same resonance energy as In were used as

[1] L. Meitner, Nature **45**, 422 (1940).
[2] L. Meitner, O. Hahn and F. Strassmann, Zeits. f. Physik **109**, 538 (1938).
[3] O. R. Frisch, Kgl. Danske Vid. Selsk. Math.-Phys. Medd. **14**, Nr. 5.
[4] C. P. Baker and R. F. Bacher, Phys. Rev. **57**, 1076 (1940).

detectors. The resonance energy of these three elements is rather well-determined and their resonance levels are known to be single. In addition, use could be made of the absorption coefficient of Th for thermal neutrons known from our earlier experiments. As already mentioned, there can be no doubt that the resonance energy of Th is beyond the energy of the neutrons strongly absorbed by Cd, hence the $1/v$ law will be valid for the absorption of thermal neutrons.

The experimental arrangement was generally as follows: The neutron source was placed inside a block of paraffin wax 3.4 cm below the surface. The detectors were placed 1.4 cm above the surface and shielded in all experiments by 0.44 mm Cd on both faces. The face opposite to the source was screened by a thick foil of the material under investigation. Between the detectors and the paraffin surface the thorium absorber (13.4 g/cm^2 of metallic Th), or other absorbers, could be inserted. The contribution to the activity of the detectors from neutrons beyond the resonance region was determined by carrying out the irradiation with absorbers of the same material and sufficiently thick to cut off practically all the resonance neutrons. One set of experiments was carried out inside paraffin with the same arrangement as had been applied for the determination of the capture cross section of thermal neutrons in Th.[1] When account is taken of the slightly changed geometrical conditions, the values found were the same as those obtained with the arrangement described above. All activity measurements were followed over several half-life periods in order to get a higher accuracy, and every experiment was repeated at least three times.

Because of the arrangement used—the detector being placed directly on the absorber of nearly equal size—one can expect that only a small part of the scattering cross section enters into the measurements. If, however, the capture cross section is small itself, the effect of scattering might be very important. Since it was not possible to determine this contribution for Th as absorber, the absorption of the resonance neutrons of In in lead was measured under the same experimental conditions. The lead absorber had the same dimensions and, within 2 percent, the same number of absorbing nuclei per cm^2 as the thorium absorber. The capture cross section for thermal neutrons in lead is known[5] to be $\sigma_{cap}^{Pb}=2.5\times10^{-24}$ cm^2, and there are good reasons to suppose that the $1/v$ law is holding for lead. So the difference between the cross section found experimentally and that one computed according to the $1/v$ law can be regarded as the contribution from scattering within the whole range of energies under investigation. However, the scattering effect implies a change in the primary directional distribution of the neutrons. In order to evaluate this influence, the relative number of neutrons indicated behind an absorber of 23.8 mg/cm^2 boron was measured with and without the lead absorber in position. With the Pb absorber inserted, the apparent absorption coefficient of boron was 10 percent larger than that one found without the lead. After applying the corresponding obliquity correction, the contribution of scattering in lead was found to be $\sigma_s=1.2\times10^{-24}$ cm^2.

From the results given below it can be seen that the scattering is important only for the absorption of the resonance neutrons of gold in Th. On account of the low absorption coefficient, these measurements are not very accurate, the difference in scattering to be expected for Pb and Th is negligible. The same holds for In and Rh, as the scattering effect is small compared to the capture process. So the absorption coefficients found experimentally for Th were corrected for the scattering contribution found with lead.

In calculating the absolute values of capture cross sections, obliquity corrections (angles up to about 70° were involved) were made according to the curves for thin, compared to thick, detectors given by Frisch,[3] without taking into account any influence of the change in the directional distribution caused by the scattering effect. We are interested only in the ratio of these cross sections to the cross section for thermal neutrons, which, as far as the latter is corrected in the same way, is independent of the applied correction. The results are given in Table I. The last column gives the cross sections calculated by assuming the validity of the $1/v$ law and by taking the capture cross section for thermal neutrons as a basis ($\sigma_{th}^{Th}=6.0\times10^{-24}$ cm^2).

[5] R. Fleischmann and W. Bothe, Ergeb. d. exakt. Naturwiss. **16**, 37 (1937). L. Meitner, reference 1.

TABLE I. *Data on cross section values.*

DETECTORS	RESONANCE ENERGY	$\sigma^{Th}_{exp.} \times 10^{24}$ CM²	$\sigma^{Th}_{cal.} \times 10^{24}$ CM²
In	0.9 ev	3.5±0.7	1.0
Rh	0.9 ev	3.5±0.7	1.0
Au	3.5 ev	~0.3	0.5

In the calculation we set $E_{th}=0.026$ ev.

The results show that, for $E=0.9$ ev, the experimental cross section is much larger than the calculated cross section, while for $E=3.5$ ev the experimental cross section appears to be somewhat smaller than that calculated according to the $1/v$ law. On account of the poor accuracy of the results it seems meaningless to calculate the exact resonance energy from the values obtained by assuming the existence of a single resonance level. Hence one can conclude only that thorium has a resonance level between 0.2 ev (cut-off energy of Cd) and 3.5 ev, and probably in the neighborhood of 2 ev.

We attempted to get additional information by carrying out some experiments with the resonance neutrons of silver ($E_r=2.5$ ev). The activities due to the resonance neutrons were, however, so low even without any absorber that it was not possible to obtain any reliable results.

The absorption of the In resonance neutrons in thin layers of boron was found to correspond to a resonance energy of 0.92±0.06 ev, if for the boron absorption coefficient of thermal neutrons the value $\mu^{B}_{th}=28$ cm²/g is taken.

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