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Slow Neutron Velocity Spectrometer Studies. III. I, Os, Co, Tl, Cb, Ge*

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The $1/v$ thermal line for iodine is $\sigma=[(3.8\pm0.2)+(1.12\pm0.05)E^{-\frac{1}{2}}]$. Crystal interference effects are apparent at low energies. There is a resonance at (20.6 ± 0.4) ev with $\sigma_0\Gamma^2\sim4$. A flat-bottomed dip at 37 ev suggests two levels at (32 ± 2) ev and (42 ± 2) ev with approximately equal values of $\sigma_0\Gamma^2\sim135$. The $1/v$ thermal line for osmium is $\sigma=[(15\pm0.4)+(2.7\pm0.1)E^{-\frac{1}{2}}]$ with crystal interference effects at low energies. There are levels at (6.5 ± 0.3) ev with $\sigma_0\Gamma^2\sim10$, at (8.8 ± 0.3) ev with $\sigma_0\Gamma^2\sim35$, at (20 ± 1) ev with $\sigma_0\Gamma^2\sim25$, probable levels at (28 ± 1.5) ev with $\sigma_0\Gamma^2\sim8$, at (42 ± 2) ev with $\sigma_0\Gamma^2\sim10$, at 84 ev and several unresolved levels above 84 ev. The $1/v$ thermal line for cobalt is $\sigma=[(6.7\pm0.3)+(6.4\pm0.15)E^{-\frac{1}{2}}]$. There is an unusually strong dip at (115 ± 5) ev with $\sigma_0\Gamma^2\sim200{,}000$ (if single) and indications of other strong unresolved levels in the region of 1000 to 10,000 ev. The $1/v$ thermal line for thallium is probably $[\sigma=(9.7\pm0.2)+(0.6\pm0.2)E^{-\frac{1}{2}}]$. There are strong crystal interference effects at low energies. There is a strong dip in the transmission curve at 270 ev and another broad dip near 1100 ev. Columbium shows only a slight $1/v$ effect $\sigma=[(6.4\pm0.2)+(0.10\pm0.04)E^{-\frac{1}{2}}]$ with strong crystal interference effects at lower energies. Only a slight dip at 4.1 ev attributed to a slight Ta impurity was found in the higher energy region. Germanium shows no $1/v$ thermal slope because of the strong crystal interference effects. There is a (perhaps multiple) level at 95 ev with $\sigma_0\Gamma^2\sim800$.

INTRODUCTION

THIS is the third of a series of papers in which the results of investigations using the Columbia University Slow Neutron Velocity Spectrometer are presented. A detailed analysis of the factors involved in the operation of the instrument and the interpretation of the data is given in previous papers.[1-4] In presenting the results of the measurements for I, Os, Co, Tl, Cb, and Ge the conventions previously adopted[3,4] are used.

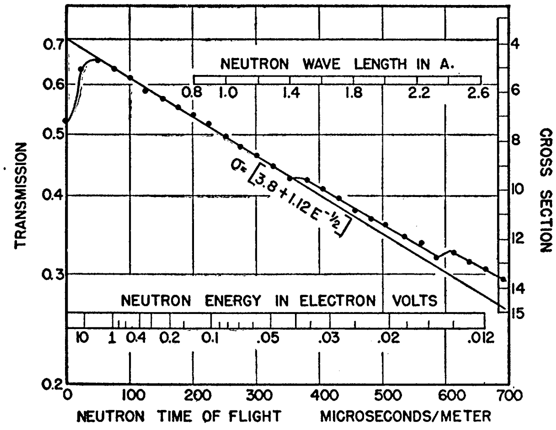

FIG. 1. The slow neutron transmission of 18.86 g/cm² of iodine. This curve indicates the presence of one or more resonance levels at high energies. From 0.04 to 3 ev the results are well matched by the relation $\sigma=(3.8+1.12E^{-\frac{1}{2}})$.

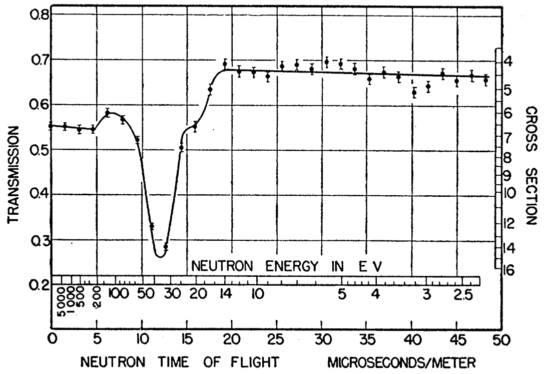

FIG. 2. The slow neutron transmission of 18.86 g/cm² of iodine. This curve shows a strong resonance dip near 37 ev with indication of another unresolved level near 20 ev.

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[1] L. J. Rainwater and W. W. Havens, Jr., Phys. Rev. **70**, 136 (1946).

[2] W. W. Havens, Jr. and L. J. Rainwater, Phys. Rev. **70**, 136 (1946).

[3] L. J. Rainwater, W. W. Havens. Jr., C. S. Wu, and J. R. Dunning, Phys. Rev. **71**, 65 (1947).

[4] W. W. Havens, C. S. Wu, L. J. Rainwater, and C. L. Meaker; Phys. Rev. **71**, 165 (1947).

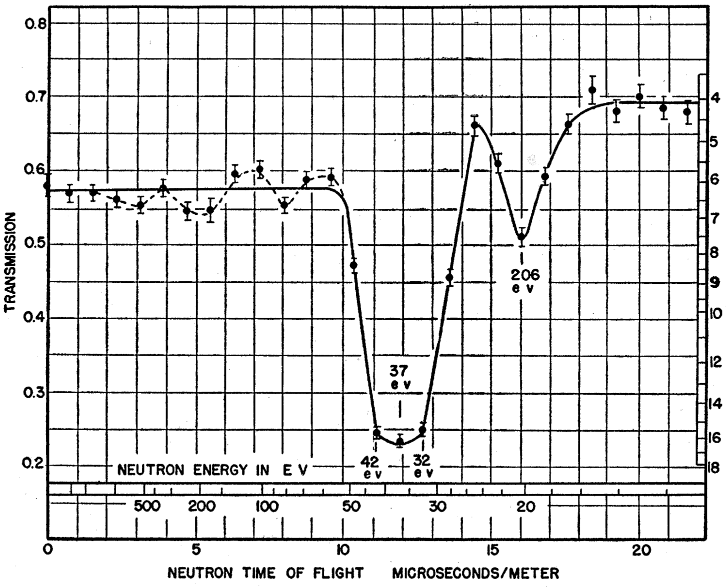

FIG. 3. The slow neutron transmission of 18.86 g/cm^2 of iodine. This curve was taken with the highest resolution of the spectrometer. The resonance at 20.6 ev is now clearly separated from the higher energy dip. The shape of the resonance dip at 37 ev suggests the presence of at least two levels probably at 32 ev and 42 ev.

RESULTS

Iodine

The slow neutron transmission of iodine was studied using an 18.86 g/cm^2 sample of analytical grade iodine packed in a thin-walled aluminum container. This sample was prepared by the Metallurgical Laboratory of the University of Chicago.

The results of the measurements using broad resolution are shown in Fig. 1. There is a dip at high energies indicating the presence of onethe more resonance levels. From 0.04 to 3 ev or results are well matched by the relation $\sigma = [(3.8+1.12)E^{-\frac{1}{2}}]$. Below 0.04 ev there is evidence of crystal interference effects with discontinuities in the transmission occurring at neutron wave-lengths of about 1.46A and 2.37A.

The energy region above 2.2 ev was next investigated with higher resolution as shown in Fig. 2. The main resonance dip is seen to occur near 37 ev with indication of another unresolved level near 20 ev. The lower transmission above 200 ev may indicate the presence of many unresolved levels.

To obtain more reliable information concerning the resonances, the region above 10 ev was investigated using the highest resolution possible with the results shown in Fig. 3. The resonance at 20.6 ev is now clearly separated from the higher energy dip. The dip at 37 ev now appears flat on the bottom where the transmission is considerably above zero. The shape of this resonance absorption curve would not be obtained if only a single resonance were present; therefore the presence of at least two levels, probably at 32 ev and 42 ev, seems reasonable. In the analysis equal $\sigma_0\Gamma^2$ values have been assumed for levels at 32 and 42 ev. The curve above 50 ev shows small irregularities that may represent weak levels near 80 ev, 200 ev, and 600 ev, but these are very uncertain. A straight line is also shown to indicate that these levels may be due to spurious effects.

Since iodine has only one isotope I^{127} all the neutron absorption effects can be assigned to this one isotope. The slow neutron induced activity in iodine is from I^{128} [5, 6] which has a half-life of 24.99 min. The results for iodine may be summarized as follows:

1. The $1/v$ thermal line is given by $\sigma = [(3.8\pm 0.2)+(1.12\pm 0.05)E^{-\frac{1}{2}}]$.
2. There are crystal interference effects below 0.04 ev with discontinuities in the transmission curve for neutron wave-lengths of about 1.46 and 2.37A.
3. The first resonance is at $E_0 = (20.6\pm 0.4)$ ev $\sigma_0\Gamma^2 \sim 4$.

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[5] Amaldi, D'Agostino, Fermi, Ponticorvo, Rasetti, and Segrè, Proc. Roy. Soc. London **A149**, 522 (1935).

[6] Tape and Cork, Phys. Rev. **53**, 676 (1938).

4. There is evidence that the next dip is due to two levels at (32±2) ev and (42±2) ev with $\sigma_0\Gamma^2$ values ~135.
5. There are doubtful indication of weak levels near 80 ev, 200 ev, and 600 ev.

Osmium

The slow neutron transmission of osmium was studied using a 17.3 g/cm² sample of metal powder. A spectrographic analysis of the sample showed less than 1 percent Si; 0.5 percent Ca, Ti, Fe, Al, Bi; 0.05 percent Cr, Mn, Pt, Cu, Au, Pb; 0.005 percent Ag; traces of Zr, V, Co, Ni, Pa, Pd, Ir, Sn, and P. For all other metals the prominent lines were not apparent; therefore the impurity was probably less than 0.05 percent for arc insensitive materials and less than 10^{-5} percent for arc sensitive materials. The sample was originally prepared at the Bureau of Standards where it was heated in purified helium for two hours at 800°C. It was then compressed into a cell under a load of 20 tons. The sample was later opened, reduced at 120°C and recapsuled. The transmission of this sample was investigated using low resolution over the full timing range as shown in Fig. 4. The best $1/v$ line (0.1 ev to 5 ev) is $\sigma=(15+2.7E^{-\frac{1}{2}})$. Below 0.1 ev there are evidences of crystal interference effects particularly near 0.028 ev and 0.015 ev corresponding to neutron wave-lengths of 1.75 and 2.36A. In addition there is a dip at higher energies.

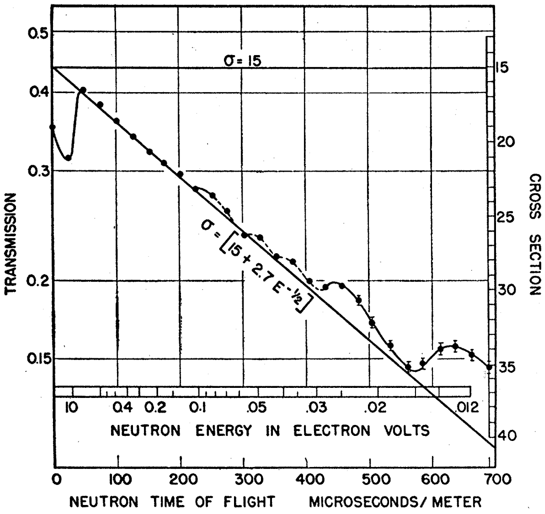

FIG. 4. The slow neutron transmission of 17.3 g/cm² of osmium. The best $1/v$ line (0.1 ev to 5 ev) is $\sigma=(15+2.7E^{-\frac{1}{2}})$. Crystal interference effects show below 0.1 ev.

The sample was next investigated using a 6.4 μsec./meter resolution width which indicated a strong dip at 8 ev and a smaller one near 80 ev. The region above 4 ev was then investigated with a 3.2 μsec./meter resolution width. The dip near 8 ev was partially resolved into two levels near 9 ev and 6 ev as in the case of the 20 ev level for iodine in Fig. 2. The results of this set of measurements showed that it would be profitable to use better resolution. Therefore the region above 4 ev was remeasured using the highest resolution with the results shown in Fig. 5. The peaks at 6.5 ev and 8.8 ev are here clearly resolved, and the peak at 20 ev is evident. The curve above 20 ev stays well below the line $\sigma=15$ representing the constant term in Fig. 4.

The dips at 84 ev and 42 ev are small, but the fact that they are probably real is indicated by the fact that they repeated on the several separate portions of the data which were combined for Fig. 5. The dip at 28 ev is less certain although it is also repeated in separate portions of the data.

Using the line $\sigma=15$ (from Fig. 4) as the value of the transmission due to scattering alone, the shape of the curve suggests that one or more levels are present at 28 ev, 42 ev, and 84 ev and that there are unresolved levels above 84 ev. The rise in transmission near zero time of flight is probably because of a decrease in the scattering cross section at higher energies.

Osmium has 7 stable isotopes to which the levels may be ascribed. Os^{189} is the most abundant (16.1 percent) odd isotope and thus may be responsible for the strong levels.[7] The activities assigned to the (n, γ) reactions in osmium are the 32-hr. Os^{191} and the 17-day Os^{193}.[8]

The results for Os may be summarized as follows:

1. The $1/v$ line in the thermal region is well represented by the equation: $\sigma=[(15\pm0.4)+(2.7\pm0.1)E^{-\frac{1}{2}}]$.
2. There is evidence of crystal interference effects at lower energies particularly for

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[7] H. A. Bethe, Phys. Rev. **332**, 50 (1936).

[8] Kurtchatow, Latychew, Nemenow, and Selinow, Physik. Zeits. Sowjetunion **8**, 589 (1935); Seaborg and Friedlander, Phys. Rev. **59**, 400 (1941); Zingg, Helv. Phys. Acta **13**, 219 (1940).

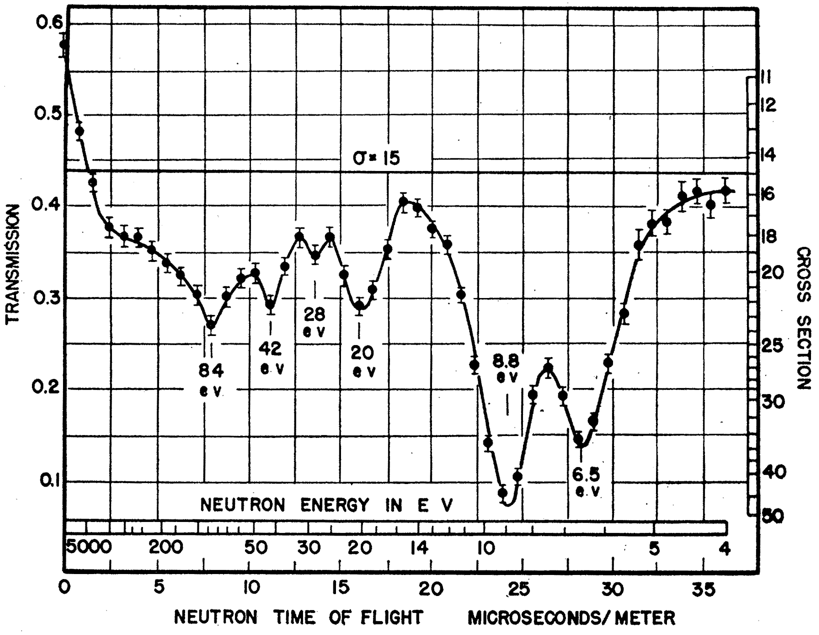

FIG. 5. The slow neutron transmission of 17.3 g/cm^2 of osmium. This curve was taken with the highest resolution of the spectrometer.

neutron wave-lengths of about 1.75 and 2.36A.

3. There is a level at $E_0 = (6.5 \pm 0.3)$ ev $\sigma_0\Gamma^2 \sim 10$.
4. There is a level at $E_0 = (8.8 \pm 0.3)$ ev $\sigma_0\Gamma^2 \sim 35$.
5. There is a level at $E_0 = (20 \pm 1)$ ev $\sigma_0\Gamma^2 \sim 25$.
6. There is probably a level at (28 ± 1.5) ev $\sigma_0\Gamma^2 \sim 8$ (to within a factor of 10).
7. There is a level at $E_0 = (42 \pm 2)$ ev $\sigma_0\Gamma^2 \sim 10$ (to within a factor of 5).
8. There is a level at $E_0 = (84 \pm 6)$ ev with other unresolved levels above this value.

Cobalt

The slow neutron transmission of cobalt was investigated using a 12.4 g/cm^2 sample of cobalt metal powder. Since this was too thick for the resonance region measurements, a thinner sample of 1.06 g/cm^2 was also employed. A spectrographic analysis of the sample showed less than 0.5 percent P, Si, Mn; 0.05 percent Mg, Ca, Fe, Cu, B, Al; 0.005 percent Ni, As; traces of Be, Cr, Mo, Ag, In, Ge, Sn, and Pb. For all other metals the prominent lines were not apparent.

The results of the measurements using broad resolution are shown in Fig. 6. Because of the sample thickness the region below 0.15 ev was not studied. The results below 5 ev are well matched by the $1/v$ line. $\sigma = (6.7 + 6.4E^{-\frac{1}{2}})$, and a dip is seen at higher energies.

The sample was next measured with good resolution above 0.5 ev as shown in Fig. 7. The same $1/v$ line (determined from Fig. 6) is used

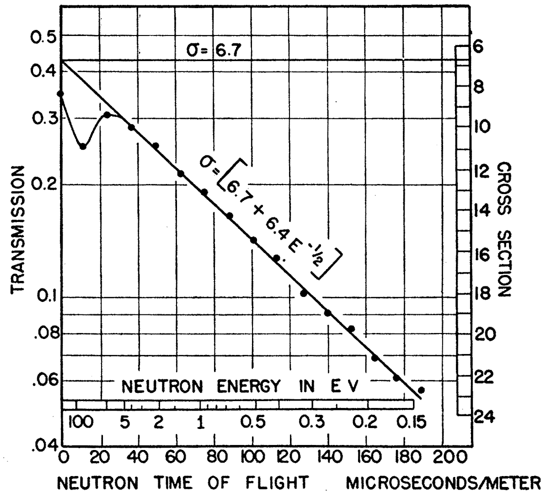

FIG. 6. The slow neutron transmission of 12.4 g/cm^2 of cobalt. The results below 5 ev are well matched by the $1/v$ line $\sigma = (6.7 + 6.4E^{-\frac{1}{2}})$. A dip is seen at higher energies.

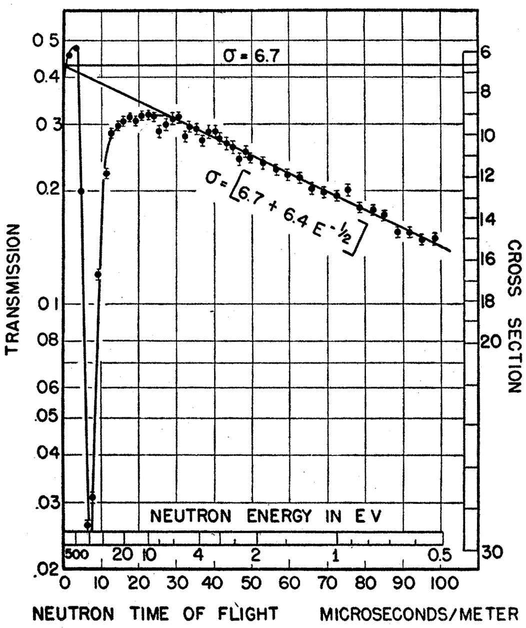

FIG. 7. The slow neutron transmission of 12.4 g/cm^2 of cobalt. This figure shows a strong dip near 100 ev and another small dip at zero time of flight.

with excellent agreement. This figure shows a strong dip near 100 ev and another small dip at zero time of flight.

The region above 50 ev was measured using the thinner sample with maximum resolution as shown in Fig. 8. The shape of the dip at 115 ev is approximately the shape that would be expected for a single strong level at this point although this dip may be due to multiple unresolved levels. The cross section indicates that in the region from 1000 to 10,000 ev there are probably several strong unresolved levels.

The level at 115 ev if single, is an exceptionally strong level with $\sigma_0\Gamma^2\sim200{,}000$ as determined from the magnitude of the resonance dip. If the $1/v$ slope is assumed to be entirely attributed to a single level at 115 ev a value of $\sigma_0\Gamma^2\sim30{,}000$ is obtained. This is much smaller than the other value but is still extremely large for a single resonance level. The lower value calculated from the $1/v$ slope may indicate that the dip at 115 ev is multiple or may represent the interference effects of the strong levels above 1000 ev on the thermal cross section. Because of the observed strength of levels in cobalt they are all probably caused by the main Co^{59} isotope of 99.83 percent abundance. Co^{60} [9] induced by the (n, γ) reaction has two isomeric states with half-lives of 5.3 yr. and 10.7 min.

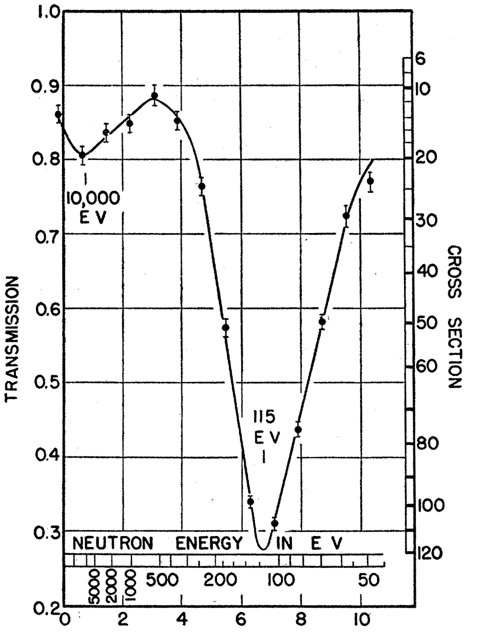

FIG. 8. The slow neutron transmission of 1.06 g/cm^2 of cobalt. This curve was taken by using a thinner sample and maximum resolution.

The results for cobalt may be summarized as follows:

1. The results below 5 ev are well matched by the $1/v$ relation $\sigma=[(6.7\pm0.3)+(6.4\pm0.15)E^{-\frac{1}{2}}]$.
2. There is a strong dip indicating a resonance at $E_0=(115\pm5)$ ev $\sigma_0\Gamma^2\sim200{,}000$ if the dip is because of a single strong resonance. If the $1/v$ slope is attributed to a single level at 115 ev then $\sigma_0\Gamma^2\sim30{,}000$. The dip may be owing to several unresolved strong levels.
3. There is evidence of other strong unresolved levels in the region of 1000 to 10,000 ev.

Thallium

The slow neutron transmission of thallium was studied using a sample containing 52.09 g/cm^2 of the material. A spectrographic analysis of the sample showed less than 0.05 percent Ca, Pb; 0.005 percent Fe, Cu, Al; traces of Mg, Cr, Mn,

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[9] Livingood and Seaborg, Phys. Rev. **60**, 913 (1941); Deutsch and Elliott, Phys. Rev. **62**, 558 (1942).

Cd, Si. For all other metals the prominent lines were not apparent.

The region above 0.015 ev was investigated using broad resolution as shown in Fig. 9. This shows that crystal interference effects are strong enough to make the determination of the $1/v$ slope difficult. The region above 0.5 ev was remeasured using better resolution as shown in Fig. 10. From this the $1/v$ line may be expressed as $\sigma=[(9.7\pm0.2)+(0.6\pm0.2)E^{-\frac{1}{2}}]$. This curve also shows the presence of a strong dip at several hundred volts energy with a rise in transmission well above the line $\sigma=9.7$. This rise in transmission near zero time of flight probably represents a decrease in the scattering cross section at still higher energies ($>50{,}000$ ev for example).

The high energy region above 50 ev was next investigated with maximum resolution as shown in Fig. 11. The shape of the curve suggests that there is a strong level at 270 ev and another strong level near 1100 ev although a number of unresolved levels may be present to give the observed curve. A rough analysis of the strength of the level at 270 ev, if single, indicates that $\sigma_0\Gamma^2\sim20{,}000$, a very strong level. If the $1/v$ slope is attributed entirely to a single level at 270 ev, the value $\sigma_0\Gamma^2\sim11{,}000$ is indicated. Thallium has two isotopes of about 30 percent and 70 percent abundance to which the levels must be ascribed. The two slow neutron induced activities in thallium[10] have half-lives of 4.23 min. and 3.5 yr.

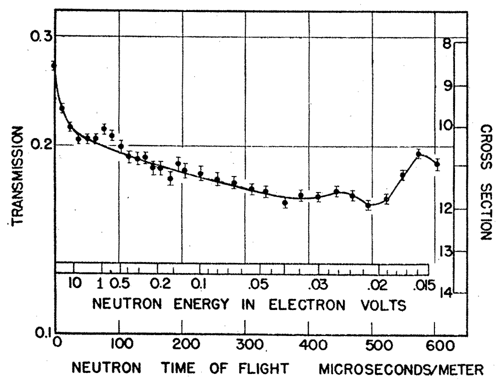

FIG. 9. The slow neutron transmission of 52.09 g/cm² of thallium. This curve was obtained by using broad resolution. The crystal interference effects are prominent.

Columbium

The slow neutron transmission of Cb was studied using a 19.37 g/cm² disk of Cb metal. A spectrographic analysis of the sample showed less than 1 percent Ta; 0.5 percent Zr; 0.05 percent Ca, Y, Zn; 0.005 percent Be, Sc, Ti, Ni, Rh, Pd, Si; traces of V, Cr, W, Mn, Fe, Ca, Au, Al, Ga, Sn, Bi. For all other metals the prominent lines were not apparent. The results of the measurements using broad resolution over a large energy range are shown in Fig. 12. This shows the presence of a slight dip near 4 ev, a slight $1/v$ slope above 0.05 ev and pronounced crystal interference effects at lower energies. In

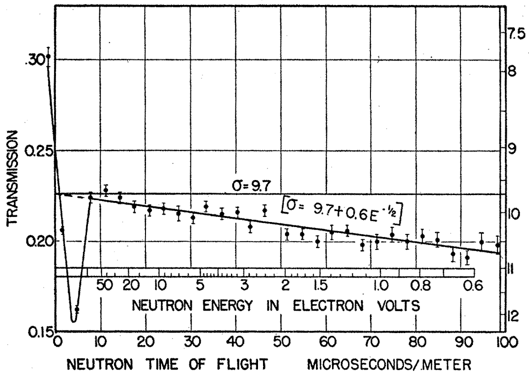

FIG. 10. The slow neutron transmission of 52.09 g/cm² of thallium. This curve represents the region above 0.5 ev as measured with better resolution. The $1/v$ line may be expressed as $\sigma=[(9.7\pm0.2)+(0.6\pm0.2)E^{-\frac{1}{2}}]$. There is also a strong dip at several hundred volts.

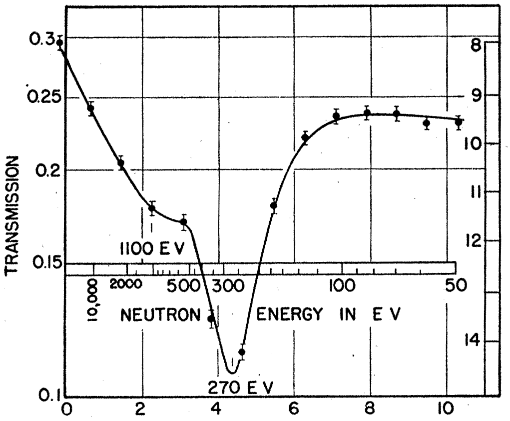

FIG. 11. The slow neutron transmission of 52.09 g/cm² of thallium using the maximum resolution of the spectrometer. The curve shows a strong main level at 270 ev and another strong level near 1100 ev. Both dips may be owing to several levels.

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[10] Pool, Cork, and Thornton, Phys. Rev. **52**, 239 (1937); Heyn, Nature **139**, 842 (1937); Fajans and Voigt, Phys. Rev. **60**, 619 (1941).

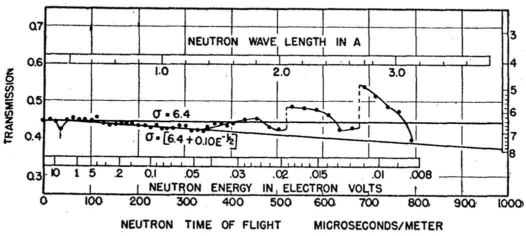

FIG. 12. The slow neutron transmission of 19.37 g/cm^2 of columbium. Pronounced crystal interference effects are evident at lower energies. The best $1/v$ line is $\sigma=(6.4\pm0.2)+(0.10\pm0.04)E^{-\frac{1}{2}}]$.

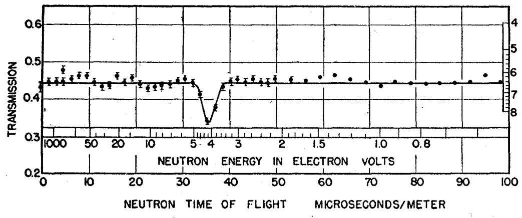

FIG. 13. The slow neutron transmission of 19.37 g/cm^2 of columbium. The transmission of neutrons above 0.5 ev is quite constant except the weak dip at 4.1 ev which can be attributed to an 0.4 percent Ta impurity.

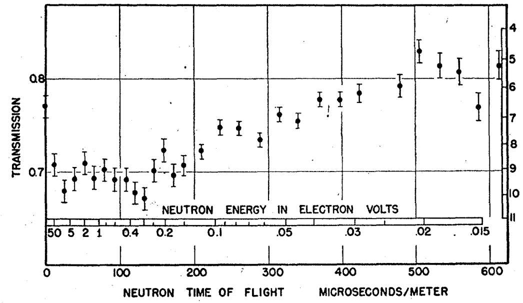

FIG. 14. The slow neutron transmission of 4.70 g/cm^2 of germanium. This represents the measurements as obtained by using broad resolution over a wide energy range. The presence of the crystal interference effects makes the determination of $1/v$ line impossible.

particular there are sharp discontinuities in the transmission corresponding to neutron wavelengths of about 2.05 and 2.67A. The best $1/v$ line is $\sigma=[(6.4\pm0.2)+(0.10\pm0.04)E^{-\frac{1}{2}}]$.

The region above 0.5 ev was then studied with good resolution as shown in Fig. 13. The transmission is quite constant except for the weak dip at 4.1 ev. This dip has been attributed to a slight Ta impurity.[4] From the area of the dip this could be accounted for by an 0.4 percent Ta impurity which is not unreasonable. Thus no levels have been found which can be attributed to Cb itself. Cb has only the single isotope Cb^{93}.

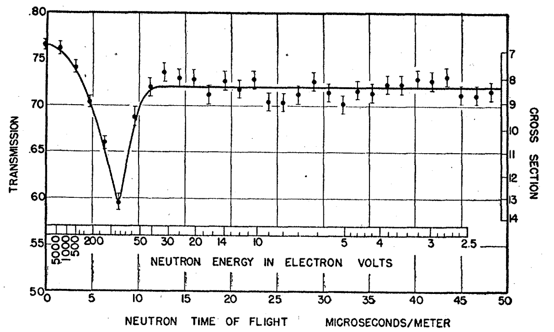

FIG. 15. The slow neutron transmission of 4.70 g/cm^2 of germanium. This represents the region above 2.2 ev as studied with good resolution.

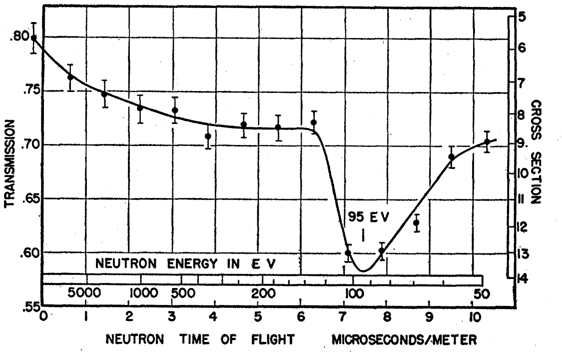

FIG. 16. The slow neutron transmission of 4.70 g/cm^2 of germanium. This region is explored using maximum resolution. The dip near 95 ev may be multiple in view of its peculiar shape.

The Cb^{94} nucleus would be of the unstable odd Z even A type, and this probably accounts for the absence of observable levels.[7, 5] Nevertheless, an induced activity in Cb by an (n, γ) reaction has been identified.[11] It has a half-life of 6.6 min.

Germanium

The slow neutron transmission of Ge was studied using a 4.70 g/cm^2 disk of Ge metal. A spectrographic analysis of the sample showed less than 0.1 percent of Fe; 0.05 percent Ca, Cr, Si; 0.005 percent of W; traces of Mg, Mo, Mn, and Cu. For all other metals the prominent lines were not apparent. The results of the measurements using broad resolution over a wide energy range are shown in Fig. 14. Crystal interference

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[11] Pool, Cork, and Thornton, Phys. Rev. **52**, 239 (1937); Sagane, Kojima, Miyamoto, and Ikawa, Proc. Phys. Math. Soc. Japan **22**, 174 (1940).

effects in the thermal region makes the determination of the $1/v$ slope impractical. The region above 2.2 ev was next studied using good resolution as shown in Fig. 15. This shows a small dip near 90 ev. The region above 50 ev was then studied using maximum resolution as shown in Fig. 16. This shows a dip near 95 ev which may be multiple in view of the shape of the dip. If it is because of a single level at 95 ev then $\sigma_0\Gamma^2 \sim 800$. The rise in transmission above 10,000 ev probably indicates a decrease in the scattering cross section at higher energies. There are five stable isotopes in germanium. The three well established activities[12] induced in germanium by (n, γ) reactions are 40 hr. Ge^{71}, 89 min. Ge^{75}, and 12 hr. Ge^{77}.

We take pleasure in acknowledging our indebtedness to Professor J. R. Dunning for his valuable suggestions and stimulating discussions. We wish to thank Miss Miriam Levin, who assisted with the numerous calculations involved in this paper, and the other members of the cyclotron staff who aided with these measurements.

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[12] Sagane, Phys. Rev. **55**, 31 (1939); Sagane, Miyamoto, and Ikawa, Phys. Rev. **59**, 904 (1941).

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The Electrical Charge on Precipitation at Various Altitudes and Its Relation to Thunderstorms

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The free electrical charges on individual precipitation particles were measured at various altitudes up to 26,000 feet by an induction method that avoided touching them. In a weak cold front exhibiting no thunderstorm activity, and having the freezing level at 11,000 feet, positive charges averaging 0.033 e.s.u. were observed from 10,000 to 26,000 feet. Negative charges averaging 0.04 e.s.u. were measured from the surface up to 20,000 feet. Positive charges were not observed below 10,000 feet and negative ones were not detected above 20,000 feet. Between these levels a mixture existed. The free charge on a large number of the particles was so great that the electric field at their surface was an appreciable fraction of the breakdown field for air, showing that powerful electrifying agencies exist even under rather quiet frontal conditions. Electric field measurements on the airplane showed that the particle charges were largely neutralized by nearby charges, presumably on the air or on the tiny cloud droplets. It is shown that the removal of this neutralizing charge will immediately produce thunderstorm electric fields and potentials. A time plot of the electric field on the surface of a flying airplane during the interval of a lightning strike is given.

Although it has been two centuries since Benjamin Franklin flew his kite to demonstrate the electrical character of lightning, little real progress has been made in the fundamental understanding of the electrical charge generating and transferring processes in thunderclouds. Because every lightning discharge in a cloud profoundly changes the electrical state within it, surveys of the cloud capable of detailed interpretation must be completed in a time short compared to the charging time. This means that an active thunderhead must be explored in something less than 10 seconds or, if a longer time is necessary, a steady state cloud must be chosen in which the convective activity is so low that disruptive electrical discharge does not take place. The Army-Navy Atmospheric Electricity Research Project has had assigned to it a Flying Fortress that has been instrumented to investigate the electrical state of the lower atmosphere. This airplane has flown through almost every conceivable type of weather during the past two years to determine the character and magnitude of the electrical effects associated with cloud and storm formations.[1]

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[1] Gunn, Hall, and Kinzer, "The Precipitation-Static Interference Problem and Methods for its Investigation," Proc. Inst. Rad. Eng. **34**, 156P April (1946).