The thermal fission cross section of U^{232} has been measured as 81 ± 15 barns[2] (the reported value being corrected here for the more recent U^{232} half-life of 71.7 years[3]). The fission cross section of U^{232} has been measured as a function of energy by James[4] up to 400 eV. Berreth[5] has reported upon the total cross section of U^{232} from 0.01 to 1000 eV. An analysis based upon the resonance parameters estimated by James indicates that only about 1/4 of the thermal fission cross section and 1/10 of the thermal capture cross section can be accounted for from the known resonances. This suggests the presence of a negative energy resonance, and a departure from a '$1/v$' dependence in the thermal region. The capture resonance integral estimated from the resonance parameters is 220 barns compared to our directly measured value of 280 barns. However the uncertainty in the value computed from resonance parameters is probably of the order of 50%. Our value of 78 barns for the thermal capture cross section can be compared with Elson's old estimate of 200 $^{+300}_{-200}$ barns and Berreth's total cross section of 230 barns. The large uncertainty in Elson's value limits the usefulness of its comparison here. However, subtracting 95 barns for fission and scattering from Berreth's 230 barn value yields 135 barns for the capture cross section of U^{232}.

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Criticism of "A Note on the Measurement of the Transport Mean Free Path of Thermal Neutrons in Graphite by a Poison Method"

In a recent note[1] an attempt was made by Price to resolve the discrepancy between pulsed values of the transport mean free path, λ_t, and steady-state values in graphite. The pulsed methods were assigned an average value of 2.59 cm, and a value of 2.77 ± 0.05 cm derived from a copper-poison technique by J. M. Hendrie, *et al.*[2] was listed.

If a three-parameter fit is made to pulsed data, the decay constant α may be expressed as

$$\alpha = v\Sigma_a + D_B B^2$$
$$= v\Sigma_a + (D_0 - CB^2)B^2 \quad (1)$$

where D_B is the diffusion constant for the spectrum in the finite moderator, D_0 for the spectrum in the infinite moderator (i.e. no leakage), and C is the so-called diffusion cooling coefficient. For $\frac{1}{v}$ absorption the infinite-medium spectrum is Maxwellian at room temperature. If C is positive the spectrum is cooler than the room-temperature Maxwellian. For the copper-poison method, which is steady state, $\alpha = 0$ since there is no decay. The author assumed $B^2 = -\frac{1}{L^2}$, which is true for a steady-state infinite-medium geometry where the spectrum is warmer than a Maxwellian at room temperature. In a source-free region $\nabla^2 n - \frac{n}{L^2} = 0$. The buckling is negative and equal to the material buckling, $B_m{}^2 = -\frac{1}{L^2}$. If B^2 is set equal to $-\frac{1}{L^2}$ for a finite geometry, the tacit assumption is made that a finite steady-state system has the same spectrum as an infinite system, which is untrue.

Actually, in the case of graphite, supercooled neutrons may be obtained by passing neutrons down a narrow column. The diffusion cooling is enormously enhanced by Bragg effects. An effective 'buckling' $B_e{}^2$, must be found that goes to zero when the leakage cooling balances the diffusion heating, and becomes positive when the cooling exceeds the heating.

In the copper-poison experiments, graphite-copper stacks with an extrapolated area of 123 × 123 cm^2 were fed by a thermal column. The diffusion length was determined by the equation

$$\frac{1}{L^2} = \frac{1}{b^2} - \frac{2\pi^2}{a^2} \quad (2)$$

where b is the measured relaxation length. Of the six stacks, I would estimate that the three least poisoned cases (including pure graphite) have spectrums cooler than room temperature. A more appropriate effective buckling may be the sum of

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TABLE I

Transport Averages

Parameter	Carbon	Water
$\bar{\lambda}_t$	0.9995 λ_0	1.074 λ_0
$\frac{\overline{\lambda_t v}}{\bar{v}}$	0.9917 λ_0	1.218 λ_0
$(\lambda)_{\bar{v}}$	0.9975 λ_0	1.093 λ_0

The second average, $\frac{\overline{\lambda_t v}}{\bar{v}}$, is also the flux-weighted average of λ_t. In the case of carbon the averages agree within one percent.

the material and leakage (not the geometric) bucklings, $B_e^2 = -\frac{1}{L^2} + \frac{2\pi^2}{a^2}$; however, this expression has not been derived rigorously.

Probably the best approach would be to correct all the diffusion lengths directly to the room-temperature spectrum. The diffusion equation, $D_0\nabla^2 n - n v\Sigma_a = 0$ can also be corrected for spectral changes and becomes

$$(D_0 - CB_e^2)\nabla^2 n - n v\Sigma_a = 0 ,$$

$$\nabla^2 n - \frac{n}{L^2} = 0 ,$$

$$L^2 = \frac{D_0 - CB_e^2}{v\Sigma_a} = \frac{D_0\left(1 - \frac{CB_e^2}{D_0}\right)}{v\Sigma_a} = L_0^2\left(1 - \frac{CB_e^2}{D_0}\right)$$

where L_0 is the diffusion length for a Maxwellian spectrum at room temperature. For infinite geometry, where it is agreed $B_e^2 = -\frac{1}{L^2}$, the usual relationship

$$L^2 = L_0^2 + \frac{C}{D_0} = \frac{D_0}{v\Sigma_a}\left(1 + \frac{v\Sigma_a C}{D_0^2}\right)$$

can be obtained.

In addition, the extrapolation length measurements exhibited a reasonably constant behavior as a function of copper poison and are inconsistent with a 5.4% decrease in λ_t because of diffusion heating.

At Hanford, diffusion length measurements have been made in a heated graphite stack coupled to a thermal column[3]. Since

$$L^2 = \frac{D_0}{v\Sigma_a} = \frac{\overline{\lambda_t v}}{3\bar{v}\Sigma_a} ,$$

L^2 should vary as $\bar{v}$ or $T^{\frac{1}{2}}$ if λ_t and $\overline{v\Sigma_a}$ are constant. The best fit to the measurements was $L^2 \sim T^{0.48 \pm 0.01}$ or $\lambda_t \sim T^{-0.02 \pm 0.01}$. In the poison experiments, if λ_t is assumed constant, $\bar{v} = \bar{v}_0\left(1 - \frac{C}{D_0}B_e^2\right)$ where $\bar{v}$ is the actual mean velocity of a stack and $\bar{v}_0$ is the Maxwellian averaged velocity at room temperature. In the most heavily poisoned case the mean velocity would be about 0.3% greater than the room temperature average, or the effective temperature 0.6% greater. (For an infinite geometry the effective temperature is 1.0% greater than ambient.) This will cause a negligible change in λ_t. It should be pointed out that the poison measurements in carbon permit determination of λ_t by two equations: (a) $\Delta X = 0.7104\ \lambda_t$ where ΔX is the extrapolation distance and (b) $D_0 = \frac{\overline{\lambda_t v}}{3}$ where $\frac{1}{D_0}$ is the slope of the $\frac{1}{L^2}$ versus Σ_a poison curve. The extrapolation value of 2.74 ± 0.03 cm is in good agreement with the value derived from the copper-poison D_0. The pulsed D_0 values, however, are consistently low.

For carbon, using $\lambda_t = \lambda_0\left(\frac{T}{T_0}\right)^{-0.02}$, averages involving λ_t are given over a Maxwellian spectrum,

$$n(T)dT = \frac{2\pi}{(\pi T_0)^{\frac{3}{2}}}\, e^{-\frac{T}{T_0}}\, T^{\frac{1}{2}}\, dT . \qquad (3)$$

For comparison, averages are given for water at a density of 1.0 g/cm^3 where $L^2 \sim T^{0.87}$ or $\lambda_t = \lambda_0(T/T_0)^{0.37}$, is assumed[4] and λ_0 is the transport mean free path at 0.025 eV. The transport mean free path at the mean velocity, $(\lambda)_{\bar{v}}$ is also included.

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[4]M. REIER and J. A. DeJUREN, *Reactor Sci. Tech.* (J.N.E. Parts A/B) 14, 18-24 (1961).

Reply to Remarks by J. A. DeJuren on "A Note on the Measurement of the Transport Mean Free Path of Thermal Neutrons in Graphite by a Poison Method"

There are at least five methods by which the transport mean free path of thermal neutrons, λ_t,