

Equating the two above expressions, and solving for total emissivity, ϵ , yields:

$$\epsilon = \frac{(-dT/dt) WC_p}{(T^4 - T_a^4) A\sigma} \quad (3)$$

This is designated the "slope method" as it depends on a value of the slope of the cooling curve.

An alternative method is to equate Equations (1) and (2), and obtain the following differential equation:

$$\left(-\frac{dT}{dt}\right) = \frac{\sigma A}{C_p W} \epsilon (T^4 - T_a^4) \quad (4)$$

If it is assumed that the quantity $(\sigma A/C_p W) \epsilon$ is independent of temperature, and that $T^4 \gg T_a^4$, one can solve the above differential equation, and obtain the following expression for ϵ :

$$\epsilon = \frac{1}{3} \frac{C_p W}{\sigma A} \left[\frac{1}{t_2 - t_1} \right] \left[\frac{1}{T_2^3} - \frac{1}{T_1^3} \right] \quad (5)$$

This is designated the "two-point method" since it requires time and temperature values from two points on the cooling curve. The resulting value is an average value between T_1 and T_2 .

A third method is to calculate emissivity from the time of an arrest in the cooling curve due to a phase transition. This would be calculated by the expression:

$$\epsilon = \frac{\Delta H/\Delta t}{T^4 - T_a^4} \frac{W}{A\sigma} \quad (6)$$

Four runs were made directly with highly polished cubes. The finish appeared somewhat mottled after only slight heating, presumably because of anisotropic growth. Four runs were made in which the polished specimens were deliberately oxidized. Oxidation was achieved by introducing measured quantities of pure oxygen to the Pyrex bulb and heating the specimen in place to about 400°C for approximately ten minutes. Following oxidation, the bulb was evacuated and the run started. In this procedure the oxidized surface suffered no damage from handling.

Tables II and III give the results. The emissivity values given under "slope method" are the average of four or more values calculated by Eq. 3 in the temperature region in question. The "two-point" values were computed between the high and low temperature values in the γ and β phase regions.

Cubes oxidized to 20,000 $\mu\text{g O}_2/\text{sq cm}$ resulted in excessive flaking and surfaces covered with loosely clinging flakes and powdery material evidently acting as radiation shields. Therefore, no data is reported for heavily oxidized specimens.

REFERENCES

1. Chemical Engineering Division Summary Report, April, May, June, 1962, ANL-6569, p. 136 (August 1962).
2. Chemical Engineering Division Summary Report, October, November, December, 1961, ANL-6477, p. 168 (March 1962).

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Note on Spectrum Hardening for Non $1/v$ Cross Sections

Effective thermal neutron cross sections are well known to depend on the thermal neutron spectrum which is determined by the moderator and neutron absorbers of the medium. While the detailed absorption properties have been accurately measured, determination of the moderator scattering kernel represents a more difficult problem. For an H_2O moderator, considerable success in duplicating measured neutron spectra has been achieved with both a free proton model (1) and with the Nelkin kernel (2, 3). However, both of these models represent somewhat crude approximations. A detailed experimental investigation of the kernel is being carried out (4, 5). In this connection it is necessary to understand for what values of the parameters, including the incident neutron energy, the kernel is most important.

The point of the present note is to present some evidence that for non $1/v$ absorbers the kernel for incident neutron energies of 0.625 eV and higher energies is significant.

The energy 0.625 eV is a conventionally used value for the upper limit of the thermal group, and the effect of the kernel for energies above this value appears in a solution of the transport equation as a source term. The source terms for the free proton model and the Nelkin model have different energy dependence, so that the sensitivity of the spectrum to the source term may be investigated by using the source for one model with the kernel (for energies below 0.625 eV) for the other model.

For a moderator with $kT_M = 0.0255$ eV, the free proton model has a source term with an energy dependence proportional to $\text{erf}[(E/kT_M)^{1/2}]$. The Nelkin model source has an energy dependence given by the same form of function but with a different value of the temperature parameter;

TABLE I
MACROSCOPIC ABSORPTION CROSS SECTIONS (cm^{-1}) FOR DIFFERENT KERNELS AND SOURCE SPECTRA

Composition	Free proton	Diff.	Nelkin kernel free proton source	Diff.	Nelkin kernel Nelkin source
Pure H_2O	0.01913	0.5%	0.01905	0.13%	0.01903
B^{10} , H_2O , 3.15 b	0.1546	3.4%	0.1508	0.9%	0.1494
B^{10} , H_2O , 6.04 b	0.2642	4.8%	0.2556	1.3%	0.2522
Cd , H_2O , 2.67 b	0.1940	0.4%	0.1942	0.5%	0.1933
Cd , H_2O , 5.4 b	0.3712	1.1%	0.3712	1.1%	0.3673
Cd , H_2O , 9.6 b	0.5898	2.3%	0.5868	1.8%	0.5762
Cd , H_2O , 15.4 b	0.8183	3.8%	0.8089	2.6%	0.7882
Sm^{149} , H_2O , 1.97 b	0.1518	1.6%	0.1509	1.0%	0.1494
Sm^{149} , H_2O , 3.67 b	0.2548	2.7%	0.2522	1.7%	0.2481
Sm^{149} , H_2O , 6.20 b	0.3682	4.1%	0.3621	2.4%	0.3536
Sm^{149} , H_2O , 8.71 b	0.4517	5.2%	0.4418	2.9%	0.4293

the source is proportional to $\text{erf} [(E/kT_s)^{1/2}]$ where $kT_s = 0.117$ ev.

To test the sensitivity to the source term, infinite medium spectra have been obtained using the free proton model as such, the Nelkin model as such, and the Nelkin kernel with the free proton source. The compositions treated correspond to the measured spectra of Beyster *et al.* (3). Table I shows macroscopic absorption cross sections averaged over the spectrum for each composition for the three models used. The percentage differences of values for the free proton model and for the Nelkin kernel with free proton source from values for the Nelkin kernel are indicated. The absorbers and absorption cross section at 2200 m/sec are shown in the first column of the table.

The differences between the Nelkin kernel values for the two sources are significant. Moreover, it is especially noteworthy that for the non $1/v$ cross sections, the major part of the difference between the free proton model values and the Nelkin model values is associated with the source term.

The Nelkin model is based on the short collision time approximation (6) which improves in accuracy with the incident neutron energy. This is supported by some comparisons of theoretical and experimental values of the scattering law for particular values of the energy and momentum transfer (7). Of the three models in Table I, the values obtained from the Nelkin model are almost certainly the most accurate.

However, the significant point of Table I is that the spectra for non $1/v$ cross sections are sensitive to the source term. On this ground, experimental investigation of the kernel for energies above 0.625 ev would be of interest.

REFERENCES

1. H. J. AMSTER, *Nuclear Sci. and Eng.* **2**, 394 (1957).
2. M. S. NELKIN, *Phys. Rev.* **119**, 741 (1960).
3. J. R. BEYSTER, J. L. WOOD, W. M. LOPEZ, AND R. B. WALTON, *Nuclear Sci. and Eng.* **9**, 168 (1961).
4. P. A. EGELSTAFF, *Nuclear Sci. and Eng.* **12**, 250 (1962).
5. P. A. EGELSTAFF AND P. SCHOFIELD, *Nuclear Sci. and Eng.* **12**, 260 (1962).
6. G. C. WICK, *Phys. Rev.* **94**, 1228 (1954).
7. D. T. GOLDMAN AND F. D. FEDERIGHI, *Trans. Am. Nuclear Sci.* **4**, 135 (1961).

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The Time Scale of Neutron Slowing Down in Water

Measurements on the time behavior of neutrons during the slowing down process have started at the 5.5 Mev van de Graaff accelerator at Studsvik, Sweden. The neutrons

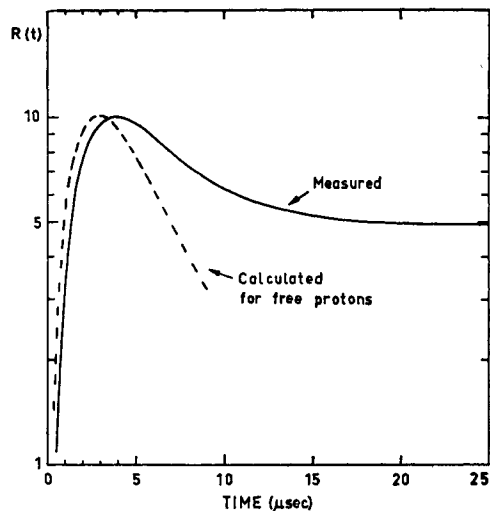


FIG. 1. Reaction rate $R(t)$ (arbitrary units) between the slowing down flux and cadmium as a function of time.

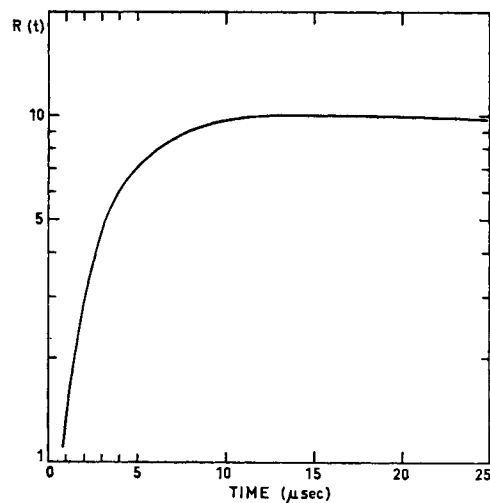


FIG. 2. Reaction rate $R(t)$ (arbitrary units) between the slowing down flux and gadolinium as a function of time.

are generated in bursts by the Li (p, n) reaction in a target inserted in a large volume of water. A small amount of a neutron absorber can be placed at a chosen position in the moderator. The rate of neutron capture in the absorber is dependent on the flux spectrum and the capture cross section of the absorber. The capture gamma rays are detected by a fast scintillation counter, the pulses from which are fed to a multichannel time analyzer.

In the first experiments very dilute solutions of cadmium and gadolinium salts, contained in 250 cm³ plastic bottles, were used. The time resolution was about 0.2 μsec. The source neutrons had a mean energy of 0.5 Mev. Figure 1 and 2 show the observed capture rate as a function of time for the cadmium and gadolinium experiments respectively. The center of the absorber was 9.5 cm from the target. The curves are corrected for overlap and dead-time, and the contribution from neutron capture in water is subtracted.

In Fig. 1 the capture rate increases to a maximum at 3.8 μsec, corresponding to the slowing down into the cadmium resonance region. From the shape of the cadmium cross