A NEUTRON ABSORPTION ALIGNMENT CHART

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A NEUTRON ABSORPTION ALIGNMENT CHART

By

Robert G. Nisle

INTRODUCTION

The problem of selecting absorbing foils or monitoring wires for the measurement of neutron flux density involves the determination of the flux depression resulting from the introduction of the foil, or wire. A first approximation may be obtained by finding the absorption of a beam of neutrons in passing through such a foil. The equations are relatively simple when only thin foils are considered, and these equations may be solved easily by the use of alignment charts. The chart presented here is a composite of three charts designed to solve the three applicable equations. A variety of problems may be solved by their use to a first approximation at least. Two such examples are given.

THEORY

The construction of the chart is based on three equations.

1. \[ \frac{n}{n_0} = e^{-\Sigma_a x} \]
2. \[ \Sigma_a = \frac{\rho N_a}{A} \sigma_a \]
3. \[ N = \frac{\rho N_a}{A} \]

Equation (1) gives the fractional transmission, \( \frac{n}{n_0} \), of a beam of neutrons passing through a sample having a macroscopic absorption cross section, \( \Sigma_a \), and a thickness, \( x \) cm. Equation (2) defines the macroscopic absorption cross section in terms of the density, \( \rho \) grams/cc, atomic weight, \( A \), microscopic absorption cross section, \( \sigma_a \), and Avogadro's
number, No. The term, $\frac{\rho \cdot No}{A}$, appearing in equation (2), is designated by N on the chart. The three scales on the right of the chart are used to make this calculation in accordance with equation (3). In the case of certain pure materials, the value of N may be obtained from Table I.

Although these equations describe the absorption of a beam of neutrons, this chart can also be used to estimate the depression in the neutron flux density. Thus, the transmission ratio is taken to be one minus the flux depression to a first approximation.

In order to apply the chart to other than thin foils, we make the assumption that the value of the exponential function for an average thickness, $\bar{x}$, can be substituted for the average of the exponential function over all applicable values of x. This is not strictly true, but within the accuracy of the chart, it is good enough. Further, as is well known, the average distance through a solid, such that an arbitrary straight line cuts the surface in two, and only two, points is given by

$$\bar{x} = \frac{4V}{S}$$

where

$V = $ the volume

$S = $ the surface area.

By use of equation (4) it can be shown that the average thicknesses of the most common geometrical forms are given by the following equations:

$$\bar{x} = \frac{4r}{3}, \quad (sphere)$$

$$\bar{x} = \frac{2r}{1+r/L}, \quad (cylinder)$$

$$\bar{x} = d, \quad \text{when } L >> r, \quad (cylinder)$$

$$\bar{x} = 2a, \quad \text{when } a << \sqrt{S}, \quad (thin \ slab)$$

where

$r = $ radius,

$a = $ thickness,

$d = 2r = $ diameter,

$L = $ length of cylinder,

$S = $ area of thin slab.
EXAMPLES

1. Estimate the flux depression for a tantalum foil 20 mils thick; \( \sigma_a = 21 \) barns.

   For tantalum it is found from Table I that
   \[
   N = \frac{\rho N_0}{A} = 5.52 \times 10^{22}
   \]
   and from equation (7) that
   \[
   \bar{x} = 2 \times 20 = 40 \text{ mils}
   \]
   A straight edge is placed on the chart joining 21 on the \( \sigma_a \) scale and 5.52 on the \( N \) scale. The intersection with \( \Sigma_a \) is marked. This intersection is projected horizontally to meet the vertical line through 40 mils on the thickness scale. These intersect at the \( n/n_0 \) line for .90. Hence, the flux depression will be about 10 percent.

2. Find the concentration of a boric acid solution contained in a long cylindrical inert container of .5 cm inside diameter, such that the flux depression shall not exceed 15 percent.

   From equation (6a) the thickness, \( \bar{x} \), is found to be 0.5 cm.

   Find the point, \( n/n_0 = .85 \), thickness = .5 cm, on the chart.
   Project this point horizontally to meet the \( \Sigma_a \) scale. The natural boron, \( \sigma_a = 755 \) barns (neglect the absorption of the hydrogen and oxygen in boric acid). Join the point \( \sigma_a = 755 \) with the projection on the \( \Sigma_a \) scale just found and extend this line to intersect the \( N \) scale at \( 0.041 \times 10^{22} \). Hence, \( 4.1 \times 10^{20} \) nuclei of boron are required, or \( 4.1 \times 10^{20} \) molecules of boric acid. The molecular weight of boric acid is 61.84. Connect .041 \( \times 10^{22} \) on the \( N \) scale with 61.84 on the \( A \) scale and read .042 grams per cc on the \( \rho \) scale. This is approximately 4% by weight in a water solution.
### TABLE I

VALUES OF THE QUANTITY \( N = \frac{\rho N_0}{A} \) FOR VARIOUS ELEMENTS

<table>
<thead>
<tr>
<th>Element</th>
<th>Density, g/cc</th>
<th>Atomic Weight, A</th>
<th>( N \times 10^{22} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be</td>
<td>1.8</td>
<td>9</td>
<td>12.05</td>
</tr>
<tr>
<td>B(^{10})</td>
<td>2.45</td>
<td>10</td>
<td>14.76</td>
</tr>
<tr>
<td>B (Natural)</td>
<td>2.45</td>
<td>10.82</td>
<td>13.64</td>
</tr>
<tr>
<td>Mg (Natural)</td>
<td>1.74</td>
<td>24.32</td>
<td>4.31</td>
</tr>
<tr>
<td>Al</td>
<td>2.699</td>
<td>27</td>
<td>6.02</td>
</tr>
<tr>
<td>Mn</td>
<td>7.2</td>
<td>55</td>
<td>7.88</td>
</tr>
<tr>
<td>Co</td>
<td>8.9</td>
<td>59</td>
<td>9.09</td>
</tr>
<tr>
<td>Zr (Natural)</td>
<td>6.4</td>
<td>91.22</td>
<td>4.23</td>
</tr>
<tr>
<td>Cd (Natural)</td>
<td>8.65</td>
<td>112.41</td>
<td>4.63</td>
</tr>
<tr>
<td>In</td>
<td>7.28</td>
<td>115</td>
<td>3.81</td>
</tr>
<tr>
<td>Ta</td>
<td>16.6</td>
<td>181</td>
<td>5.52</td>
</tr>
<tr>
<td>Au</td>
<td>19.32</td>
<td>197</td>
<td>5.91</td>
</tr>
<tr>
<td>Ti (Natural)</td>
<td>4.5</td>
<td>204.39</td>
<td>1.33</td>
</tr>
<tr>
<td>Pb (Natural)</td>
<td>11.35</td>
<td>207.21</td>
<td>3.30</td>
</tr>
<tr>
<td>Bi</td>
<td>9.78</td>
<td>209</td>
<td>2.82</td>
</tr>
<tr>
<td>Th</td>
<td>11.3</td>
<td>232</td>
<td>2.93</td>
</tr>
<tr>
<td>U</td>
<td>18.68</td>
<td>238</td>
<td>4.73</td>
</tr>
</tbody>
</table>
INSTRUCTIONS

1. DRAW A STRAIGHT LINE THROUGH THE KNOWN VALUE P ON THE DENSITY SCALE AND A ON THE ATOMIC WEIGHT SCALE. EXTEND THIS LINE TO INTERSECT THE NUCLEI SCALE AT N.

2. DRAW A LINE BETWEEN N AND Q, ON THE CROSS SECTION SCALE. READ THE MACROSCOPIC ABSORPTION CROSS SECTION AT \( \Sigma_a \).

3. PROJECT E, HORIZONTALLY TO INTERSECT THE APPROPRIATE FRACTIONAL TRANSMISSION LINE, \( n/n_0 \) AT T. READ THE THICKNESS BY PROJECTING T VERTICALLY DOWNWARD TO THE SCALES AT THE BOTTOM OF THE CHART.

\[ \Sigma_a \] MACROSCOPIC ABSORPTION CROSS-SECTION, Cm\(^{-1}\).

\( P \) DENSITY, gms/cc.

\( A \) ATOMIC WEIGHT.

\( N \) NUMBER OF NUCLEI PER CUBE CENTIMETER.

\( n/n_0 \) FRACTIONAL TRANSMISSION, RATIO NEUTRS.OUT/NEUTRS.IN.

\( T \) THICKNESS, Cm. (Mils).

\( e \) BASE OF NATURAL LOGS.