Proton Range-Energy Relation for Eastman NTA Emulsions*

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The ranges of protons recoiling from monoergic neutrons have been used to determine a range-energy relation for Eastman NTA emulsions. The experimental results for proton energies from 1 to 17 Mev agree closely with Webb's computed range-energy relation.

A CALCULATED stopping power curve for Eastman NTA and NTB emulsions has been published by Webb.[1] This calculated stopping power was in considerable disagreement with an experimental calibration for NTB plates reported by Peck,[2] but was in fair agreement with the data of Lattes, Fowler, and Cuer[3] for Ilford B-1 emulsions which have approximately the same chemical composition. More accurate range-energy data for the Ilford C-2 emulsions have been recently published by Roblat.[4] Rotblat also reports some data which indicate that Kodak NT-2A (Eastman NTA?) emulsions have a few percent greater stopping power than the Ilford C-2.

During the past year several reactions have been investigated at Wisconsin by observing in Eastman NTA emulsions the proton recoils from neutrons. The reactions studied were $Li^7(p,n)Be^7$, $Be^9(p,n)B^9$, $Be^9(d,n)B^{10}$, $B^{10}(d,n)C^{11}$, $B^{11}(d,n)C^{12}$, and $O^{16}(d,n)F^{17}$. Details of the exposure and the measurement criteria are given in the original papers.[5–9] These data can

TABLE I. Calibration data for the range-energy curve of protons in Eastman NTA emulsions.

Reaction	Q (Mev)	Angle of observation	Mean energy of incident particles (Mev)	Mean energy of recoil protons (Mev)	Mean range of recoil protons (microns)
$Li^7(p,n)Be^7$	-1.646 ± 0.002[a]	0	3.36	1.67	32±1
		80	3.91	1.83	36±1
		0	3.91	2.23	51±2
$Be^9(p,n)B^9$	-1.852 ± 0.002[b]	90	3.80	1.37	23±1
		45	3.80	1.73	35±1
		0	3.80	1.91	39±2
		0	3.93	2.03	44±2
$Be^9(d,n)B^{10}$	$+4.363\pm0.016$[c]	80	3.41	6.66	296±7
		0	3.41	7.78	387±12
$B^{10}(d,n)C^{11}$	$+6.473\pm0.011$[d]	80	3.40	8.78	503±16
		80	3.64	8.94	492±17
		0	3.64	10.15	634±11
$B^{11}(d,n)C^{12}$	$+13.740\pm0.014$[e]	80	3.40	15.57	1271±55
		0	3.40	16.93	1536±48
$B^{11}(d,n)C^{12*}$	$+9.302\pm0.020$[f]	80	3.40	11.44	752±25
		0	3.40	12.63	897±16
		0	3.64	12.88	971±18
$O^{16}(d,n)F^{17}$	-1.63 ± 0.01[g]	0	3.06	1.32	22±1
		10	3.06	1.32	21±1
		20	3.06	1.30	21±1
		30	3.06	1.28	20±1
		90	3.06	1.01	14±1

[a] Herb, Snowdon, and Sala, Phys. Rev. **75**, 246 (1949).
[b] Richards, Smith, and Brown, Phys. Rev. **80**, 524 (1950).
[c] Computed from $Q=(2D-He^4)-(Q_d+Q_{dp}+Q_{d\alpha})$, where $(2D-He^4)=23.842\pm0.008$ Mev [Ewald, Z. Naturforsch. **5**, 1 (1950)]. $Q_d=2.226\pm0.003$ [Mobley and Laubenstein, Phys. Rev. **80**, 309 (1950)] and Q_{dp} and $Q_{d\alpha}$ are the MIT values for $B^{10}(d,p)B^{11}$ and $B^{11}(d,\alpha)Be^9$ [Strait, Van Patter, Buechner, and Sperduto, Phys. Rev. **81**, 747 (1951)].
[d] Computed from $B^{10}(d,p)B^{11}$ and $B^{11}(p,n)C^{11}$ with Q_{dp} from Strait, *et al.* (footnote c); and Q_{pn} is from Richards, *et al.* (footnote b).
[e] Computed from $Q=(2D-He^4)-(Q_d+Q_{dp'}+Q_{d\alpha'})$, where the quantities are the same as in footnote c except the primed Q's refer to Strait, *et al.*'s values for $C^{12}(d,p)C^{13}$ and $C^{13}(d,\alpha)B^{11}$.
[f] Computed from Malm and Buechner's value for the C^{12} excited state, 4.438 ± 0.014 Mev (Phys. Rev. **81**, 519 (1951)) and the above Q value for the ground-state transition.
[g] F. Ajzenberg, unpublished threshold determination.

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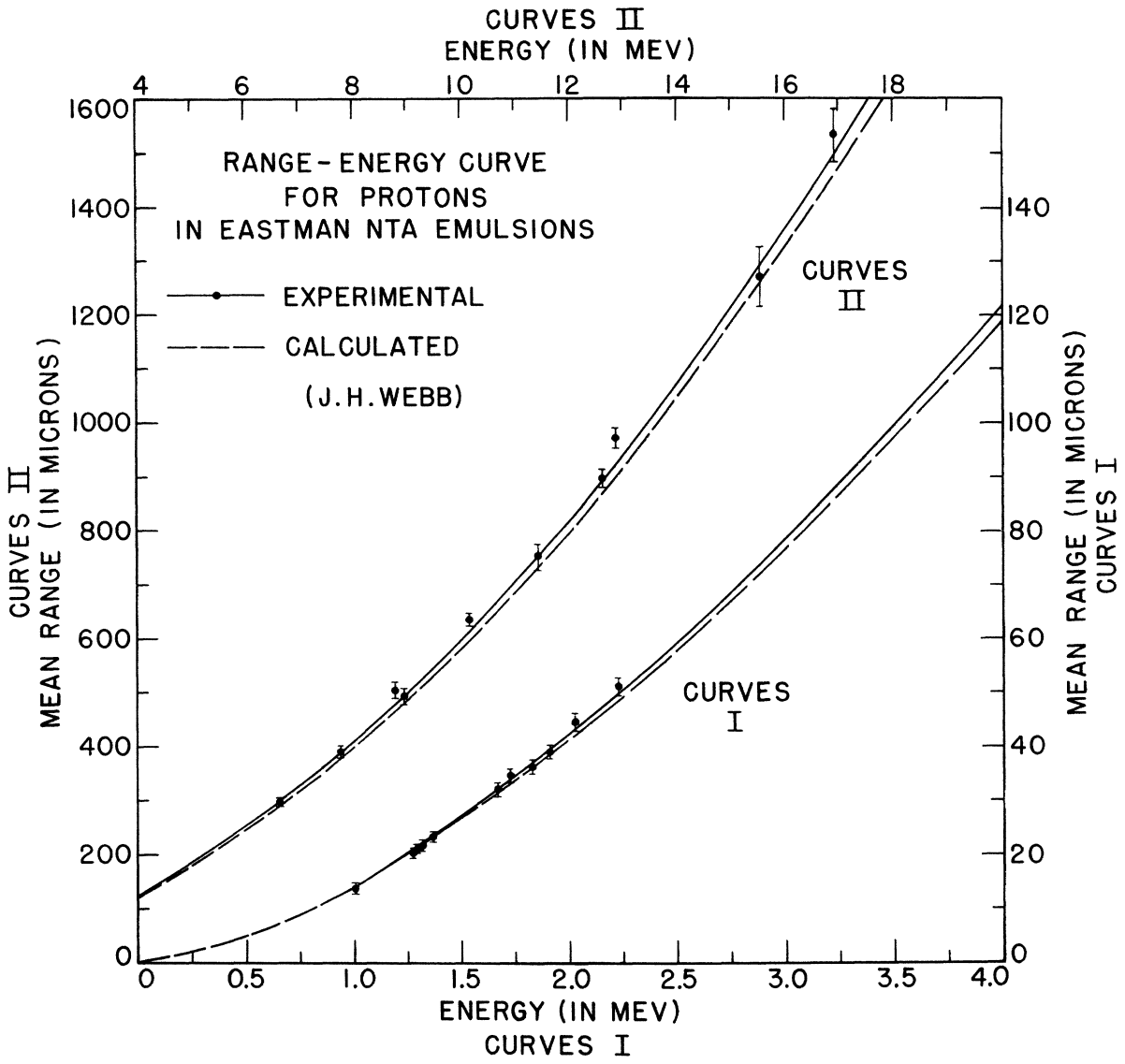

FIG. 1. Range-energy curve for protons in Eastman NTA emulsions. Both curves refer to emulsions used under ordinary laboratory humidity conditions.

be used for calibration points on a range-energy curve for protons stopped in Eastman NTA emulsions. The data cover a range of proton energies from about 1 to 17 Mev. The uncertainty in recoil proton energy is much smaller than the experimental mean range determination in most cases since the reaction Q values are known to about 0.5 percent or better, the bombarding energy to 0.1 percent, and the uncertainty in target thicknesses does not appreciably increase the energy uncertainty. The uncertainty in mean range indicated in Table I and in the figure is 0.675 times the root-mean-square deviation of all track lengths in the group.

All the data are summarized in Table I and in Fig. 1. The figure also includes Webb's range-energy curve[1] which is calculated for an emulsion whose effective stopping power is closely the same as the Eastman NTA, NTB, and the Ilford B-1 and C-2 emulsions. The calculated and observed range-energy curves are now in satisfactory agreement, though the experimental data do indicate a slightly lower stopping power than Webb's calculations. In fact, the smooth curve drawn through the experimental points of Fig. 1 is exactly 2 percent higher than Webb's calculated curve.

It should be emphasized that Webb's calculations and our experimental data refer to plates used under ordinary relative humidity conditions (around 60 percent), and if emulsions are used under vacuum conditions the stopping power may be several percent higher (for example, see reference 4.)