

**If information seems to be missing,
make any reasonable assumptions.**

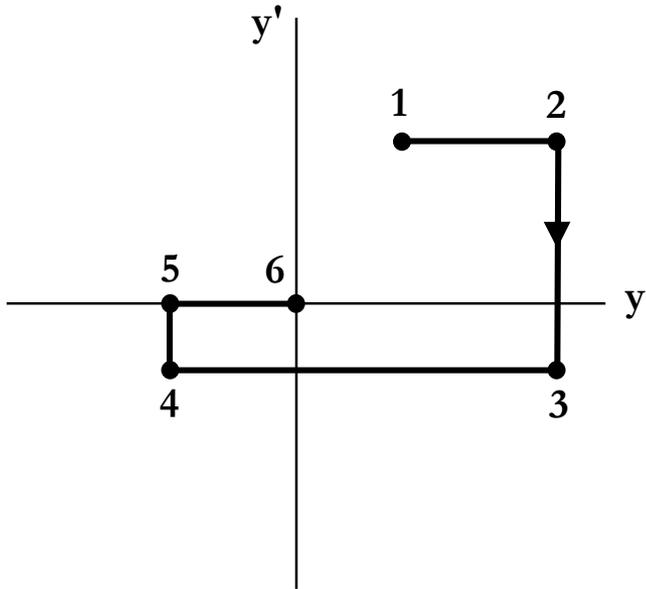
1. A target has an areal density of 2.3 g/cm^2 and a thickness of 0.8 inch. What is the density of the target material?
2. A 100 MeV proton goes through 1 inch of Lexan (density 1.2 g/cm^3 , $S/Q = 6.9 \text{ MeV}/(\text{g/cm}^2)$ at 100 MeV). How much energy does it lose?
3. A cylindrical air-filled ionization chamber has a gap (thickness) of 1 cm and a radius of 1 cm. It is exposed to 0.1 nA of 200 MeV protons ($S/Q = 4.0 \text{ MeV}/(\text{g/cm}^2)$) spread uniformly over the area. What is the dose rate to air? How much energy is deposited in the air in 1 sec?
4. An average person radiates heat at a rate of about 100 Watts. A whole-body radiation dose of 4 Gy is lethal in about 50% of cases in a few weeks, even with good medical care. How much time does it take the body to radiate an equivalent amount of energy?
5. How many 200 MeV protons does it take to deliver 1 Gy to 1 liter (1000 cm^3) of water?
6. You are asked to treat a cylindrical volume, 10 cm in radius and 20 cm deep (treat to surface) with passive beam spreading at a dose rate of 2 Gy/min. If your double scattering system is 45% efficient, how many protons/sec do you need at the first scatterer?

7. A cylindrical Gaussian is 5% down at a radius of 2 cm. At what radius is it 10% down? What fraction of the protons lie inside the 10% radius?
8. Design a 160 MeV single scattered beam to treat (to maximum depth) a 5 cm radius field with a transverse dose uniformity of $\pm 5\%$, using a pristine Bragg peak (no range modulation). You have 200 cm from the scatterer to the target. What is the treatment depth (d_{80})? If the input proton current is 1 nA, what is the dose rate at the peak?
9. If you wanted to use the same beam energy to treat to a depth of 10 cm (still no modulation), what changes would you make? What would be the new dose rate at the peak?
10. Compute and verify the mass stopping power, and its error, of 110 MeV protons in aluminum. The mean excitation energy according to ICRU49 Table 2.8 is 166 ± 2 eV.
11. How much energy do 150 MeV protons lose in 1 inch of aluminum?
12. 200 MeV protons enter a stack consisting of 0.5 cm Pb and 10 cm Lexan. What is their residual range in water?
13. How much Lexan will reduce the residual range of 160 MeV protons to 3 cm in water?
14. What is the water equivalent of 0.5 cm Pb at 200 MeV? at 100 MeV?
15. A 200 MeV proton beam with an energy spread of 3 MeV is degraded to 90 MeV in Lexan. What is its approximate energy spread at 90 MeV?

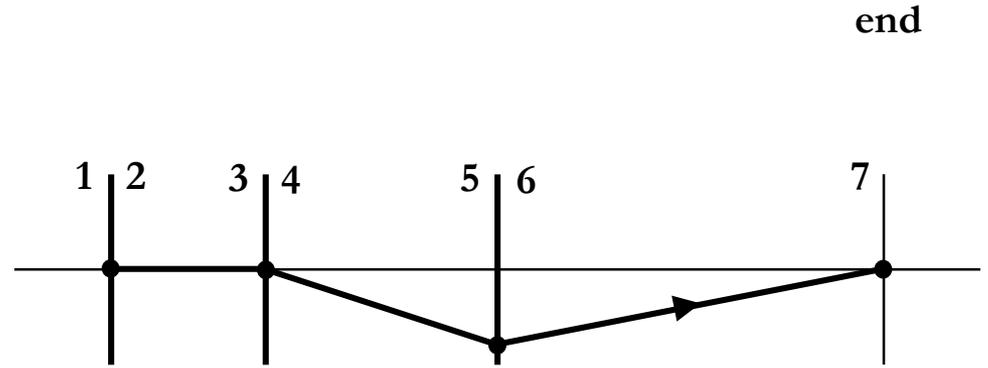
16. A cylindrical Gaussian probability density is 5% down at a radius of 2 cm. At what radius is it 10% down? What fraction of the protons lie inside the 10% radius?
17. Compute the rms projected multiple scattering angle of 100 MeV protons incident on 1 mm of water, or 1 m of air, or 1 mm of Pb using a) Rossi's formula and b) Highland's formula. Present your results as a table, and include the ratio Rossi/Highland.
18. In a multiple scattering experiment, 160 MeV protons are incident on 1 g/cm² of a mystery target. The dose distribution on a screen 200 cm from the downstream target face is Gaussian with an rms width of 1.234 cm. What is the mystery material? What is the energy loss in it? What is the energy loss in air, and the contribution of air to the rms width? What assumptions and approximations did you make?
19. 100 MeV protons hit a Pb/Lexan binary degrader. a) For 50 mrad and 80 MeV out, what thicknesses of Pb and Lexan do I need? b) Same, for 15 mrad and 80 MeV out.
20. The next page shows the phase space $\mathbf{y}'(\mathbf{y})$ trajectory of a proton. Sketch its actual space trajectory in a side view, $\mathbf{y}(\mathbf{z})$.
21. The next page shows the actual space trajectory $\mathbf{x}(\mathbf{z})$ of a proton. Sketch its phase space trajectory $\mathbf{x}'(\mathbf{x})$.
22. For the simple beam line shown on the next page compute, at the end of the beam line, the proton energy, beam size, emittance, angular spread, angular confusion, and virtual point source. Use Highland's formula.

23. At $z = 0$ a beam has rms projected horizontal size 2 mm, rms projected angular divergence $\theta_{\text{RMS}} = 5$ mrad and emittance 10π mm mrad . a) Is it converging or diverging? b) What is its x_{RMS} at $z = 1$ m?

problem 20:



problem 21:



problem 22:

