

9. (a) The charge that strikes the surface in time Δt is given by $\Delta q = i \Delta t$, where i is the current. Since each particle carries charge $2e$, the number of particles that strike the surface is

$$N = \frac{\Delta q}{2e} = \frac{i \Delta t}{2e} = \frac{(0.25 \times 10^{-6} \text{ A})(3.0 \text{ s})}{2(1.6 \times 10^{-19} \text{ C})} = 2.3 \times 10^{12} .$$

- (b) Now let N be the number of particles in a length L of the beam. They will all pass through the beam cross section at one end in time $t = L/v$, where v is the particle speed. The current is the charge that moves through the cross section per unit time. That is, $i = 2eN/t = 2eNv/L$. Thus $N = iL/2ev$. To find the particle speed, we note the kinetic energy of a particle is

$$K = 20 \text{ MeV} = (20 \times 10^6 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV}) = 3.2 \times 10^{-12} \text{ J} .$$

Since $K = \frac{1}{2}mv^2$, then the speed is $v = \sqrt{2K/m}$. The mass of an alpha particle is (very nearly) 4 times the mass of a proton, or $m = 4(1.67 \times 10^{-27} \text{ kg}) = 6.68 \times 10^{-27} \text{ kg}$, so

$$v = \sqrt{\frac{2(3.2 \times 10^{-12} \text{ J})}{6.68 \times 10^{-27} \text{ kg}}} = 3.1 \times 10^7 \text{ m/s}$$

and

$$N = \frac{iL}{2ev} = \frac{(0.25 \times 10^{-6})(20 \times 10^{-2} \text{ m})}{2(1.60 \times 10^{-19} \text{ C})(3.1 \times 10^7 \text{ m/s})} = 5.0 \times 10^3 .$$

- (c) We use conservation of energy, where the initial kinetic energy is zero and the final kinetic energy is $20 \text{ MeV} = 3.2 \times 10^{-12} \text{ J}$. We note, too, that the initial potential energy is $U_i = qV = 2eV$, and the final potential energy is zero. Here V is the electric potential through which the particles are accelerated. Consequently,

$$K_f = U_i = 2eV \implies V = \frac{K_f}{2e} = \frac{3.2 \times 10^{-12} \text{ J}}{2(1.60 \times 10^{-19} \text{ C})} = 10 \times 10^6 \text{ V} .$$