1. (6.30 Proton in space)

\[ K = 10^6 eV = \frac{1}{2} m v^2 \]

\[ v = \left( \frac{2 \times 10^6 \text{eV}}{m} \right) = \left( \frac{2 \times 10^6 \times 1.6 \times 10^{-19} \text{J}}{1.673 \times 10^{-27} \text{kg}} \right)^{\frac{1}{2}} = 1.4 \times 10^7 \text{m/s} \]

\[ R = \text{radius of curvature of path} \]

\[ \frac{m v^2}{R} = q v B \Rightarrow R = \frac{m v}{q B} \]

convert gauss to Tesla

\[ B = 3 \times 10^{-6} \text{gauss} \times \frac{10^{-4} \text{T}}{\text{gauss}} = 3 \times 10^{-10} \text{T} \]

\[ R = \frac{1.673 \times 10^{-27} \text{kg} \times 1.4 \times 10^9 \text{m/s}}{1.6 \times 10^{-19} \text{C} \times 3 \times 10^{-10} \text{T}} = 4.8 \times 10^8 \text{m} \]

\[ t_{\text{rev}} = \frac{2 \pi R}{v} = \frac{2 \pi \cdot 4.8 \times 10^8 \text{m}}{1.4 \times 10^7 \text{m/s}} = 2.2 \times 10^3 \text{sec} \]
Proton in space)

RELATIVISTIC VERSION AS IN BOOK

\[ K = 10^{16} \text{ eV} \]

At this high energy, the proton is moving very close to the speed of light and we need to use the relativistic expression for the kinetic energy in terms of speed.

\[ K = (\gamma - 1) m_0 c^2 = (\gamma - 1) 938 \times 10^6 \text{ eV} \Rightarrow \gamma = 1.0 \times 10^6 \text{ as in book} \]

Definition of \( \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \) so \( v = (1 - \frac{1}{\gamma^2}) c = 3.0 \times 10^8 \text{ m/s} \)

to given precision

Also, we have to convert gauss to Tesla: \( 1 \text{T} = 10^4 \text{ gauss} \)

\[ B = 3 \times 10^{-6} \text{ gauss} = 3 \times 10^{-10} \text{T} \]

\[ R = \frac{\gamma m v}{q B} = \frac{0.7}{1.6 \times 10^{-19} C \cdot 3 \times 10^{-10} \text{T}} = 1.0 \times 10^{17} \text{ m} \]

where we have used the expression for \( R \) from Ex. 6.29

\[ t = \frac{2\pi R}{v} = 2\pi \times 10^{17} \text{ m} = 2.1 \times 10^9 \text{ s} \approx 70 \text{ years} \]

\[ \sqrt{3 \times 10^8 \text{ m/s}} \]
Physics 272, Fall 2018  Problem 2

\[ F_{top} = I \left( 0, -a, 0 \right) \times (k \frac{a}{2}, \frac{a}{2}, 0) \]
\[ F_{top} = I \left( 0, 0, \frac{1}{2} k a^2 \right) \]
\[ F_{bot} = I \left( 0, a, 0 \right) \times (k \frac{a}{2}, -\frac{a}{2}, 0) \]
\[ F_{bot} = I \left( 0, 0, \frac{1}{2} k a^2 \right) \]

\[ F_{left} + F_{right} = 0 \quad \text{because if you look at a small segment } dz \]
on the left, and the corresponding one on the right, both have the same length and
\[ B \text{-field (their } z \text{-coordinates are the same), but their currents are opposite, so} \]
\[ \text{so } dF_{left} + dF_{right} = I (L \times B) + (-I) (L \times B) = 0 \]

\[ F_{tot} = F_{top} + F_{bot} + F_{left} + F_{right} \]
\[ F_{tot} = I \left( 0, 0, \frac{1}{2} k a^2 \right) + I \left( 0, 0, \frac{1}{2} k a^2 \right) = 0 \]
\[ F_{tot} = \left( 0, 0, I k a^2 \right) = I k a^2 \frac{a}{2} \]

---

\[ \frac{F_{tot}}{k a^2} = \frac{I a}{2} \]
\[ e\gamma B = \frac{mv^2}{r} \quad T = \frac{2\pi r}{v} \]

\[ \frac{v}{r} = \frac{eB}{m} \quad T = \frac{2\pi m}{eB} \]

Time to collision is
\[
T = \frac{\pi m}{eB} = \frac{\pi \cdot 9.1 \times 10^{-31} \text{kg}}{1.6 \times 10^{-19} \times 3.53 \times 10^{-3}} = 5.1 \times 10^{-9} \text{s} \approx (5.07 \text{ns})
\]

---

**Problem 4**

View from side

\[ F_y |
\]

\[ \mu_s (mg - F_y) = F_x \]

Rule for static friction: \( F_x < \mu_s N \)

\[ \mu_s (mg - F \sin \phi) = F \cos \phi \]

Solve for \( F \) as a function of \( \phi \), then minimum with \( \phi \)

\[ \mu_s mg = F (\cos \phi + \mu_s \sin \phi) \]

\[ F = \frac{\mu_s mg}{\cos \phi + \mu_s \sin \phi} = \frac{d}{d\phi} \left( \cos \phi + \mu_s \sin \phi \right) = -\sin \phi + \mu_s \cos \phi \]

\[ \sqrt{\mu_s^2 + 1} \]

\[ F = \frac{\mu_s \sqrt{\mu_s^2 + 1}}{1 + \mu_s^2} \]

\[ = \frac{\mu_s \sqrt{\mu_s^2 + 1}}{\sqrt{\mu_s^2 + 1}} = \frac{\mu_s mg}{IL} = \frac{F_{\text{min}}}{IL} = 0.12 \text{ T} \]

5.0 N
\[ B_e = \frac{\mu_0 I}{2\pi} \] 

\[ B_e = \frac{\mu_0 I}{2\pi} \cdot \frac{1}{r^2} \] 

\[ B_e = \frac{\mu_0 I}{2\pi} \cdot \frac{1}{r} \] 

\[ \overline{B_e} = \overline{B}_1 = \overline{B}_2 \] 

\[ \overline{B} = \frac{\mu_0 I}{2\pi} \cdot \frac{1}{r} \] 

At \( P \), the fields due to wires 2 & 3, \( B_2 \) and \( B_3 \), are equal but opposite in direction due to the same current. They are also in line. Therefore, the field produced by wire 1 is just from the field produced by wire 1.