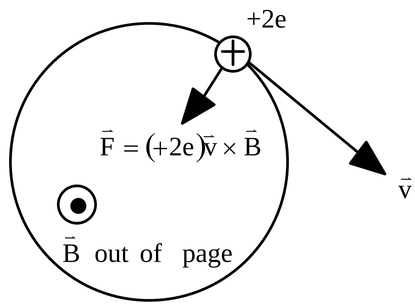
20.RQ.29

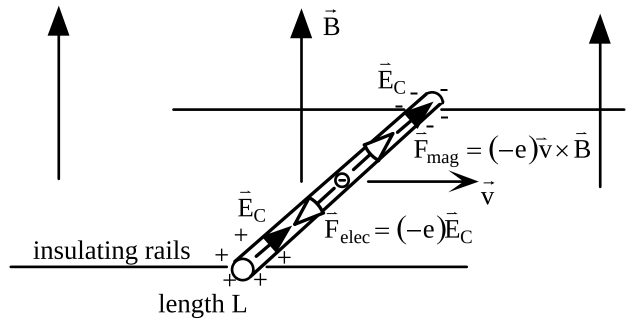


For the force to be inward (to turn the positively charged nucleus into a circular orbit), the magnetic field must be out of the page. For the magnitude, with r = radius of orbit and T = period (time for one revolution):

$$m\frac{v^2}{r} = F = 2evB\sin(90°) = 2evB \text{ (nonrelativistic approximation)}$$

$$B = \frac{mv}{2er} = \frac{m\left(\frac{2\pi r}{T}\right)}{2er} = \frac{\pi m}{eT} = \frac{\pi\left(\frac{4\times10^{-3}\text{ kg/mole}}{6\times10^{23}\text{ nuclei/mole}}\right)}{(1.6\times10^{-19}\text{ C})(80\times10^{-9}\text{ s})} = 1.6 \text{ tesla}$$

20.RQ.36



Magnetic force $(-e)\vec{v} \times \vec{B}$ on an electron inside the rod polarizes the rod as shown.

A Coulomb electric field $\vec{E}_C$ appears inside the rod as shown, due to the surface charges.

Polarization proceeds until $F_{electric} = F_{magnetic}$:

$$eE_C = evB\sin(90°) \Rightarrow E_C = vB$$

$\vec{E}_C$ is uniform throughout the rod, since $\vec{v}$ and $\vec{B}$ are the same everywhere. The surface charges will arrange themselves to make a uniform electric field.

$\Delta V \equiv -\int \vec{E}_C \bullet d\mathrm{l} = E_C L = vBL$, since $\vec{E}_C$ is uniform.

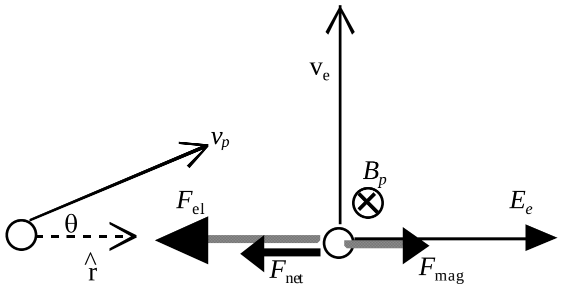
$\Delta V = emf - r_{internal}\mathrm{I} = emf$, since I = 0, so emf = $E_C L = vBL$ (1 pt).

Or, $\mathrm{emf} = \int \frac{\vec{F}_{NC} \bullet d\mathrm{l}}{q} = \frac{evBL}{e} = vBL = E_C L$.

Once the rod is polarized, $I = 0$, so there is no ILB magnetic force opposing the motion. So no force is required to keep the rod moving at a constant speed v on the frictionless rails.

Problem 20.P.44 Moving proton and moving electron

(a)



Force on electron:

Proton makes B into page at location of electron.

$$B_p = \left| \frac{\mu_0}{4\pi} \frac{e\vec{v}_p \times \hat{r}}{r^2} \right| = \frac{\mu_0}{4\pi} \frac{ev_p \sin\theta}{r^2} \text{ into page}$$

Magnetic force on electron by proton is to right.

$$F_{\text{mag}} = \left| -e\vec{v}_e \times \vec{B}_p \right| = ev_e B_p \sin 90^\circ = \frac{\mu_0}{4\pi} \frac{e^2 v_p v_e \sin\theta}{r^2}$$

Electric force on electron by proton:

$$F_{\text{el}} = \left| -e\vec{E}_p \right| = \frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} \text{ to left}$$

Net Force:

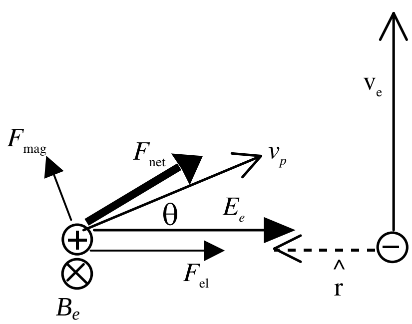
$$\vec{F}_{\text{net}} = \vec{F}_{\text{el}} + \vec{F}_{\text{mag}}$$

$$F_x = -\frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} + \frac{\mu_0}{4\pi} \frac{e^2 v_e v_p \sin\theta}{r^2}$$

$$= -\frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} \left[1 - \frac{v_e v_p \sin\theta}{c^2} \right] \text{ (since } \mu_0 \varepsilon_0 = \frac{1}{c^2}\text{)}$$

$$F_y = 0$$

(b)



Force on proton:

Electron makes B into page at location of proton.

$$B_e = \left| \frac{\mu_0}{4\pi} \frac{-e\vec{v}_e \times \hat{r}}{r^2} \right| = \frac{\mu_0}{4\pi} \frac{ev_e}{r^2} \text{ into page}$$

Magnetic force on proton by electron is to northwest:

$$F_{mag} = \left| e\vec{v}_p \times \vec{B}_e \right| = ev_p B_e \sin 90^\circ = \frac{\mu_0}{4\pi} \frac{e^2 v_p v_e}{r^2}$$

Electric force on proton by electron:

$$F_{\text{el}} = \left| e\vec{E}_e \right| = \frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} \text{ to right}$$

Net Force:

$$\vec{F}_{\text{net}} = \vec{F}_{\text{el}} + \vec{F}_{\text{mag}}$$

$$F_x = +\frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} - \left(\frac{\mu_0}{4\pi} \frac{e^2 v_p v_e}{r^2} \right) \sin\theta$$

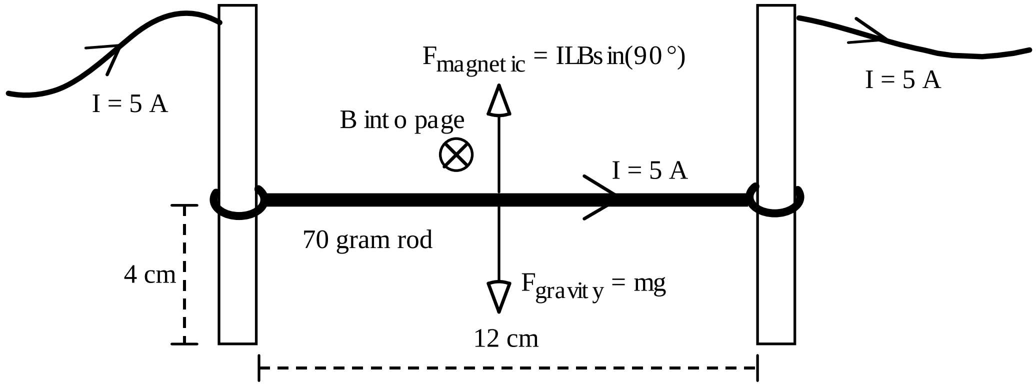
$$= \frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} \left[1 - \frac{v_e v_p \sin\theta}{c^2} \right] \text{ (since } \mu_0 \varepsilon_0 = \frac{1}{c^2}\text{)}$$

$$F_y = \left(\frac{\mu_0}{4\pi} \frac{e^2 v_p v_e}{r^2} \right) \cos\theta$$

(c) It is clear from the diagrams above that the net force on the proton is NOT equal and opposite to the net force on the electron! This is confirmed by the calculation; the x components of the force are equal and opposite, but the y components are not. Evidently Newton's third law (reciprocity) is not obeyed by magnetic forces.

(d) Total momentum of the particles is NOT conserved; they experience DIFFERENT momentum changes.

Problem 20.P.52 Magnetic levitation



In order to balance the downward force of gravity, there must be an upward magnetic force of equal magnitude, which requires a magnetic field into the page (right hand rule, with conventional current to the right).

$$ILB\sin(90°) = ILB = mg$$

$$B = \frac{mg}{IL} = \frac{(0.07\text{kg})(9.8\text{N/kg})}{(5\text{ampere})(0.12\text{m})} = 1.14\text{ tesla}$$

There could be an additional component of magnetic field to the right or left, which would exert no force on the wire: $\left|I\vec{L} \times \vec{B}\right| = ILB\sin(0°) = 0$.

$$E = \frac{0.73\text{volts}}{0.15\text{m}} = 4.9\,\text{volts/meter}$$

$$u = \frac{v}{E} = \frac{4.8\times10^{-3}\,\text{m/s}}{\left(\dfrac{0.73\text{volts}}{0.15\text{m}}\right)} = 9.9\times10^{-4}\,\frac{\text{m/s}}{\text{volts/m}}$$

Note that the electric field E in the direction of the current is much larger than the transverse field E_H.

(d) $I = qnAv$, and we assume that $q = e$. So we have

$$n = \frac{\text{I}}{eAv} = \frac{0.3\text{ampere}}{\left(1.6\times10^{-19}\text{C}\right)\left(0.08\text{m}\times0.012\text{m}\right)\left(4.8\times10^{-3}\text{m/s}\right)} = 4\times10^{23}\,\text{carriers/m}^3$$

This is a very low density of charge carriers. The density of free electrons in copper is 8×10^{28} per m^3. Evidently this slab of material is not an ordinary metal: the charge carriers are positive, and the density of charge carriers is very low.

(e) The potential difference along 15 cm of material is 0.73 volts = RI, so

$$R = \frac{\Delta V}{I} = \frac{0.73\text{volts}}{0.3\text{ampere}} = 2.4\,\text{ohms}$$