SHOW ALL WORK IN THE SPACE BELOW. NO CREDIT FOR AN ANSWER WITHOUT WORK OR AN EXPLANATION EVEN IF THE
ANSWER IS CORRECT ITSELF.

Two identical beams of electrons are travelling parallel to one another, 1.8 mm apart. Each beam delivers 10 μC per second to the target at
which they are aimed. The electrons are travelling at 4x10^8 m/s.

(A) How large is the magnetic field on electrons on one beam as a result of the other beam? (5 points)

(B) How large is the force on each electron in one beam as a result of the other beam? (5 points)

\[
(A) \quad B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7} \text{Tm} / \text{A})(10 \mu \text{A})}{2\pi \cdot (1.8 \times 10^{-3} \text{ m})} = 1.1 \times 10^{-9} \text{ T}
\]

\[
(B) \quad F = qvB \quad \text{since} \ v \ \text{is} \ \perpendicular \ \text{to} \ B
\]

\[
= \left(-1.6 \times 10^{-19} \ \text{C}\right)(4 \times 10^6 \text{ m/s})(1.1 \times 10^{-9} \text{ T}) = -7.0 \times 10^{-22} \text{ N}
\]

\[
(\text{ASIDE: since electron mass is} \ 9 \times 10^{-31} \text{ kg}, \ \text{this "tiny" force still produces} \ a = \frac{F}{m} = 7 \times 10^{-22} \text{ N} / 9 \times 10^{-31} \text{ kg} = 8 \times 10^8 \text{ m/s}^2 \ \text{=} \ 100 \ \text{milli}\text{g} \ \text{g}^{1/2})
\]
A small circular loop of wire that has an area of 3 cm² is centered on a point a distance of 0.4 m from a wire. The wire initially carries a current of 0.06 A in the plane of the paper as shown. The current then steadily increases to 0.15 A over a period of 20 sec, and then remains constant.

(A) How large is the magnetic field at the center of the loop at the start of the problem? (4 points)
(B) How large an emf is generated in the loop, and when does it occur? (6 points)

\[ B = \frac{\mu_0 I}{2\pi r} \]
\[ = \left( \frac{4\pi \times 10^{-7} \text{Tm/amp}}{2\pi \cdot 0.4 \text{m}} \right) (0.06 \text{ amp}) \]
\[ = 3 \times 10^{-8} \text{T} \]

**1 pt Eq.**
**2 pt substitutions**
**1 pt units**

(B) **EMF when \( \Phi \) changes**

\[ \Rightarrow \text{B changes} \Rightarrow \text{I changes} \]

**1 pt**

\[ \mathcal{E} = -N \frac{\Delta \Phi}{\Delta t} \]

\[ = -A \cdot \Delta B \]

**1 pt**
**1 pt \( \mathcal{E} = AB \)**

**1 pt**

\[ \Delta B = B_{\text{final}} - B_{\text{init}} \]

\[ = \frac{\mu_0 I_f}{2\pi r} - \frac{\mu_0 I_{\text{INIT}}}{2\pi r} = \frac{\mu_0}{2\pi r} (I_f - I_{\text{INIT}}) \]

**2 pt substitutions**

\[ = \frac{4\pi \times 10^{-7} \text{Tm/amp}}{2\pi \cdot 0.4 \text{m}} (0.15 \text{ amp} - 0.06 \text{ amp}) \]

\[ = 4.5 \times 10^{-8} \text{T} \]

**2 pt substitutions**

\[ \mathcal{E} = \mathcal{E} \text{ of area} \times \frac{10^{-4} \text{ m²/cm²}}{20 \text{ sec}} = 4.5 \times 10^{-8} \text{T} \]

**1 pt**
**1 pt**

\[ = 3 \text{ cm²} \times \frac{(4 \times 10^{-4} \text{ m²/cm²})}{20 \text{ sec}} = 4.5 \times 10^{-8} \text{T} \]

**1 pt**

\[ = 6.75 \times 10^{-13} \text{ volts} \]

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C=\( \frac{Q}{V} \)  \( C = \frac{A}{\varepsilon_0 d} \)  \( I = \Delta Q/\Delta t \)  \( I = V/R \)  \( P = I^2 R = I^2 V = V^2/R \)  \( R = \rho L/A \)  \( V/U/Q \)  \( E = F/Q \)  \( E = -\Delta V/\Delta z \)  \( 1 \text{ e}^- = 1.6 \times 10^{-19} \text{ C} \)

F = qv x B  \( F = 1 \ell \times B \)  \( B = \mu_0/I/2\pi r \)  \( \varepsilon = -N \Delta \Phi/\Delta t \)  \( \Phi = A B \cos \phi \)  \( \mu_0 = 4\pi \times 10^{-7} \text{Tm/amp} \)