A rail gun uses electromagnetic force to fire projectiles, rather than using explosives. Essential parts of a rail gun include two conducting rails, and a power source. A conducting armature is placed across the rails, which are bare metal. When the power source is turned it causes current to flow through the armature and an electromagnetic force then pushes the armature (and thus projectile) down the rail. (See Figure 1 on the cover.) We are considering a rail system 10 m long, 4 cm apart powered by a capacitor once the switch is thrown. The current is 4x10^4 amps. You may consider the magnetic field from the wires that hits the armature as just the same field you would find along the wire anywhere else.

B. 1. Consider a point midway between the wires, between the armature and the capacitor. Which way does the net magnetic field point there? (A) into the page (B) out of the page (C) parallel to the wire, toward the capacitor (D) parallel to the wire, away from the capacitor (E) there is no net field.

B. 2. If you reversed the direction of the current out of the capacitor (A) the projectile would be moved backward (B) the projectile would move the same direction (C) there would then be no force on the projectile.

B. 3. Compare the magnetic flux through the rail gun when the armature is at point M, exactly midway down the rail, to the magnetic flux when the armature is at point E, at the end of the rail. (A) The flux is greater when the armature is at M than at E. (B) The flux is greater when the armature is at E than at M. (C) The flux is the same for both cases because the field is the same, but it is not zero. (D) The flux is zero for both.

A. 4. Compare the induced emf induced in the rail gun when the armature has reached M, (going from the start, at the capacitor C), versus the emf induced when the armature has gone from point M to the end E. (A) More emf is induced going from M to E than C to M. (B) More emf is induced going from C to M than M to E. (C) The same emf is induced in both cases.

E. 5. Suppose you were unhappy with the voltage the capacitor gave you, and you wanted it to be 10 times greater. Suppose you connect the primary side of the transformer to the capacitor to make a bigger voltage pulse. (A) The primary could have 10 turns and the secondary 1 turn. (B) The primary could have 100 turns and the secondary 10 turns. (C) The primary could have 100 turns and the secondary should have 1 turn. (D) The primary should have one turn and the secondary 100 turns. (E) The primary could have 100 turns and the secondary 1000 turns.

SHOW ALL WORK IN THE SPACE BELOW. NO CREDIT FOR AN ANSWER, EVEN IF CORRECT, WITHOUT CLEAR WORK OR EXPLANATIONS.

6. Calculate the net magnetic field midway between the wires.

\[ B = \frac{\mu_0 I}{2\pi r} \]
\[ = \frac{2 \times 10^{-7}}{2\pi} \]
\[ = 0.8 \, \text{T} \]

7. Using the field from your answer above, and taking it as the average field on the armature, calculate the force that is applied to the armature.

\[ F = ilB \]
\[ = (4 \times 10^4 \, \text{A})(4 \times 10^{-2} \, \text{m})(0.8 \, \text{T}) \]
\[ = 1.28 \times 10^3 \, \text{N} \]
The Stanford Linear Accelerator is 3.2 km (2 miles) long according to Wikipedia and accelerates particles by electrostatic forces to near the speed of light, after which point they typically hit a target, and are observed at a detector. The mass of a muon is $1.9 \times 10^{-6}$ kg. It's charge is that of the proton, +e. When observed in a stationary laboratory, a muon's lifetime is a mere $2.2 \mu$s before it decays into other particles. Suppose a beam of positively charged muons were accelerated so they were travelling at 0.995c for almost the whole length of 2 miles, before they (or their decay products) hit the detector.

**B.** 8. Standing at the target you would observe (A) time runs fast for the muon, but the distance the muon travels is still 2 miles (B) time runs slow for the muon, but the distance the muon travels is still 2 miles. (C) time and distance for the muon are unchanged (D) time runs normally for the muon, but the distance I see the muon travel is under 2 miles (E) time runs normally for the muon, but the distance the muon must travel is more than 2 miles.

**D.** 9. If I were travelling with the muons I would see (A) time runs fast for the muon. (B) time runs slow for the muon (C) the distance to the target is more than 2 miles (regardless of what Wikipedia says) (D) the distance to the target is less than 2 miles.

**A.** 10. If I watch the approaching muons from the stationary target, (A) their charge will be unchanged (B) their mass will be unchanged (C) their momentum will be unchanged (D) their lifetime will be unchanged.

**A.** 11. Gamma rays are a high energy form of electromagnetic radiation and travel at the speed of light. If the muon were to decay, and emit a gamma ray in doing so, while the muon was in motion (A) the gamma ray still travels at the speed of light (B) the gamma ray travels at 1.995 the speed of light (C) the gamma ray speed will depend on whether it is emitted forward or backward in the direction of the muon’s travel.

**E.** 12. Suppose I tried to use a magnetic field to deflect the muons so they rise upward (against gravity) as they travel down the beam line. Which way should the field point? (A) upward (B) downward (C) along the direction the muons travel (D) opposite the directions the muons travel (E) to the right if the beam is pointed toward you (F) to the left if the beam is pointed toward you.

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13. Calculate the kinetic energy of the muon.

$$KE = mc^2 - m_0c^2 = m_0c^2 \left( \frac{1}{\sqrt{1 - (v/c)^2}} - 1 \right) = (1.9 \times 10^{-6} \text{ kg}) \left( 3 \times 10^8 \text{ m/s} \right)^2 \left( \frac{1}{\sqrt{1 - (0.995)^2}} - 1 \right) = 1.7 \times 10^{-11} \text{ J}$$

15. Does the muon arrive at the end of the accelerator (the target) before it decays?

SEVERAL WAYS TO DO THIS,

FROM TARGET, MUON LIFETIME:

$$t = \frac{t_0}{\sqrt{1 - (v/c)^2}} = \frac{2.2 \mu s}{\sqrt{1 - (0.995)^2}} = 2.2 \mu s.$$  

How far did it go in 22 μs?

$$d = vt = (0.995 \times 3 \times 10^8 \text{ m/s}) (22 \times 10^{-6} \text{ s}) = 6.6 \times 10^3 \text{ m}$$

which is > 3.2 km.  

So it makes it!

You could go with muon + watch distance decrease.
As shown in the figure to the right, a magnetic field of strength 3.5 T directed into the paper uniformly fills the space in the square abcd. A wire bent in a circle of diameter 8 cm is present as shown.

C 15 As I move the ring to the left (still inside the square), then (A) a current will be induced that goes clockwise around the wire. (B) a current will be induced that goes counterclockwise around the wire (C) no current will be induced.

C 16. If I move the ring along the field lines, thus moving below the plane of the paper, (A) a current will be induced that goes clockwise around the wire. (B) a current will be induced that goes counterclockwise around the wire (C) no current will be induced.

A 17. If I tilt the ring (A) a current will be induced that goes clockwise around the wire. (B) a current will be induced that goes counterclockwise around the wire (C) no current will be induced.

B 18. If, in a time of just 0.25 sec I stretch the wire into a rectangle of size 10 cm by 2.6 cm, when is an emf generated, if ever? (A) never (B) only while the wire shape is being changed (C) once the wire shape has taken on the rectangular shape. (D) while the wire shape is being changed, and continuing thereafter.

C 19. If I replace the uniform field with a wire that carries current along the direction ab, and then move the ring to the left (A) a current will be induced that goes clockwise around the wire. (B) a current will be induced that goes counterclockwise around the wire (C) no current will be induced.

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20 For the conditions in question 18, calculate the size of the emf induced in the wire.

\[ E = -N \frac{\Delta \Phi}{\Delta t} = -N \frac{\Delta (AB)}{\Delta t} = -B \frac{\Delta A}{\Delta t} \]

\[ A_{\text{final}} = 0.10 \text{ m} \times 0.026 \text{ m} = 2.6 \times 10^{-3} \text{ m}^2 \]

\[ A_{\text{init}} = \pi r^2 = \pi (0.04 \text{ m})^2 = 5.0 \times 10^{-3} \text{ m}^2 \]

\[ \Delta A = 2.4 \times 10^{-3} \text{ m}^2 \]

\[ E = -3.5 \text{ T} \times 2.4 \times 10^{-3} \text{ m}^2 / 0.25 \text{ sec} = 3.4 \times 10^{-2} \text{ Volts} \]