calculus-based physics-2: electricity, magnetism, and thermodynamics (phys180-02): unit 5

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UNIT 4 REVIEW

Reading: Chapters 7, 9, and 10

1. Voltage and Capacitance
2. Ohm’s Law
3. DC circuits

UNIT 4 REVIEW PROBLEMS

Which of the following would decrease the time required to charge the capacitor at right?

- A: Decreasing the capacitance
- B: Decreasing the resistance
- C: It already charges as fast as possible
- D: Both A and B

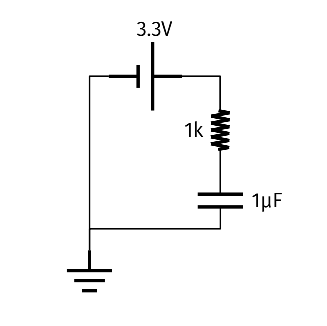


Figure 1: An RC circuit.

What is the RC time of the circuit?

- A: 1 μs
- B: 1 ms
- C: 1 s
- D: 10 s

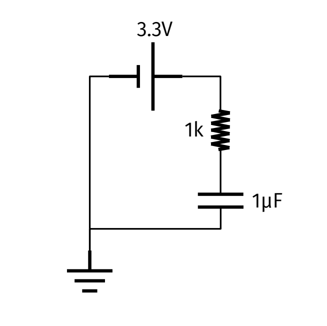


Figure 2: An RC circuit.

What is the maximum charge stored eventually in the capacitor? *Recall that $Q = CV$.*

- A: 3.3 μ C
- B: 1.5 μ C
- C: 3.3 mC
- D: 1.5 C

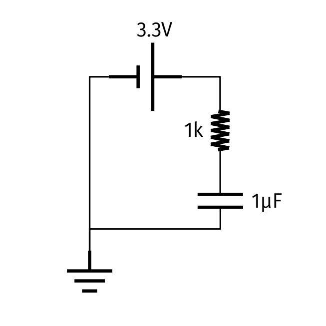


Figure 3: An RC circuit.

SUMMARY

Reading: Chapter 11

1. Magnetism and magnetic fields
2. Motion of a charged particle in a magnetic field
3. Other forces
4. Current loops

MAGNETISM AND MAGNETIC FIELDS

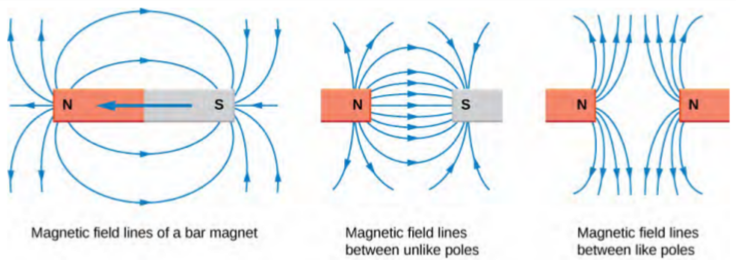


Figure 4: Various magnetic field line configurations.

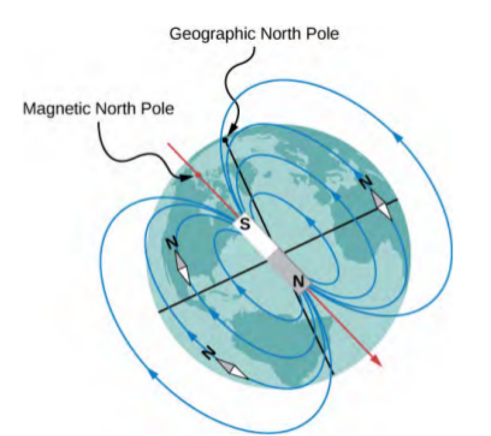


Figure 5: The magnetic and geographic poles are not the same.

It would be nice if we could say:

$$F = \mu_0 \frac{q_{m,1} g_{m,2}}{r^2} \tag{1}$$

But...we can't. Why? There's no such thing has magnetic charge:

$$\nabla \cdot \vec{E} = \rho/\epsilon_0 \tag{2}$$

$$\nabla \cdot \vec{B} = 0 \tag{3}$$

But there is a force associating charge and magnetic fields.

But first, let's review the cross-product.

What is a cross-product and how does it work?

Computing the cross product [edit]

Coordinate notation [edit]

The standard basis vectors **i**, **j**, and **k** satisfy the following equalities in a right hand coordinate system:

$$\begin{aligned} \mathbf{i} \times \mathbf{j} &= \mathbf{k} \\ \mathbf{j} \times \mathbf{k} &= \mathbf{i} \\ \mathbf{k} \times \mathbf{i} &= \mathbf{j} \end{aligned}$$

which imply, by the anticommutativity of the cross product, that

$$\begin{aligned} \mathbf{j} \times \mathbf{i} &= -\mathbf{k} \\ \mathbf{k} \times \mathbf{j} &= -\mathbf{i} \\ \mathbf{i} \times \mathbf{k} &= -\mathbf{j} \end{aligned}$$

The definition of the cross product also implies that

$\mathbf{i} \times \mathbf{i} = \mathbf{j} \times \mathbf{j} = \mathbf{k} \times \mathbf{k} = \mathbf{0}$ (the zero vector).

Figure 6: The cross-product is a way of multiplying unit vectors.

Let $\vec{v} = 2\hat{i}$ and $w = -2\hat{j}$. What is $\vec{v} \times \vec{w}$?

- A: $-4\hat{k}$
- B: $4\hat{k}$
- C: $-2\hat{i}$
- D: $2\hat{j}$

Let $\vec{v} = 3\hat{j}$ and $w = 5\hat{k}$. What is $\vec{v} \times \vec{w}$?

- A: $15\hat{i}$
- B: $5\hat{j}$
- C: $3\hat{i}$
- D: $15\hat{k}$

Let $\vec{v} = 3\hat{i} \times 3\hat{j}$ and $w = 2\hat{k}$. What is $\vec{v} \times \vec{w}$?

- A: $-6\hat{j} + 6\hat{k}$
- B: $-6\hat{j} + 6\hat{i}$
- C: $6\hat{j} + 6\hat{i}$
- D: $6\hat{k} + 6\hat{i}$

Group board exercise: Compute the following cross product:

$$\vec{v} = 2\hat{i} - 2\hat{j} \tag{4}$$

$$\vec{w} = 4\hat{j} - 4\hat{i} \tag{5}$$

$$\vec{v} \times \vec{w} = ?? \tag{6}$$

Group board exercise: Compute the following cross product:

$$\vec{v} = 2\hat{i} - 2\hat{j} + \hat{k} \tag{7}$$

$$\vec{w} = 4\hat{j} - 4\hat{i} - \hat{k} \tag{8}$$

$$\vec{v} \times \vec{w} = ?? \tag{9}$$

The Lorentz Force

Let a particle with charge q and velocity $\vec{v}$ move through a magnetic field $\vec{B}$. The Lorentz force on the charged particle is

$$\vec{F}_{\mathrm{L}} = q\vec{v} \times \vec{B} \tag{10}$$

As a helpful memory tool, we have the right-hand rule to remember the direction of the cross-product. The units of the magnetic field are the Telsa, after Nikola Tesla. We also have the Gauss which is 10^{-4} Tesla.

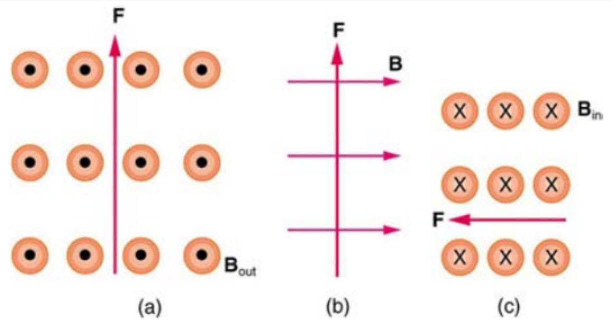


Figure 7: Three different magnetic field and charge scenarios. The vector $\vec{F}$ is the direction of the Lorentz force, and the magnetic field is uniform. A dot indicates that the magnetic field is coming out of the page, and an x indicates that the field is going into the page.

In which of the diagrams is a positively charged particle moving to the left?

- A: A
- B: B
- C: C
- D: WAT WAT WAT

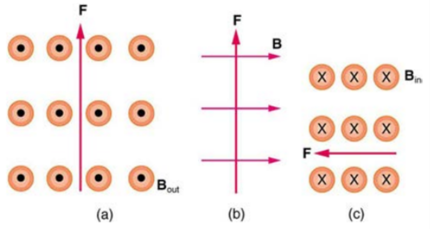


Figure 8: Three different magnetic field and charge scenarios.

In which of the diagrams is a positively charged particle moving upwards?

- A: A
- B: B
- C: C
- D: WAT WAT WAT

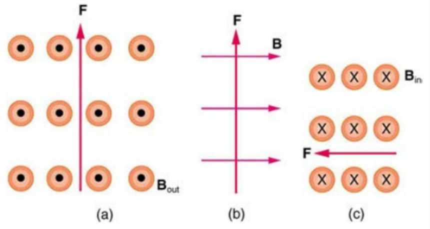


Figure 9: Three different magnetic field and charge scenarios.

In which of the diagrams is a negatively charged particle into the page?

- A: A
- B: B
- C: C
- D: WAT WAT WAT

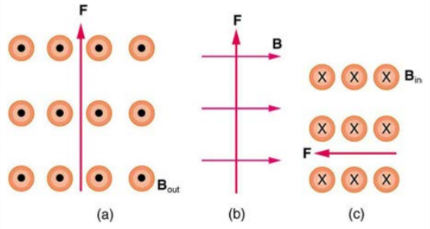


Figure 10: Three different magnetic field and charge scenarios.

In which of the diagrams is a negatively charged particle to the right?

- A: A
- B: B
- C: C
- D: WAT WAT WAT

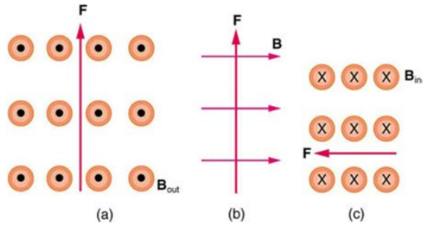


Figure 11: Three different magnetic field and charge scenarios.

A theorem for the magnitude of the cross-product: Let $\vec{a}$ and $\vec{b}$ be vectors and θ be the angle between them. The magnitude of the cross product is:

$$|\vec{a} \times \vec{b}| = ab \sin \theta \tag{11}$$

Thus, the magnitude of the Lorentz force is

$$F_{\mathrm{L}} = qvB \sin \theta \tag{12}$$

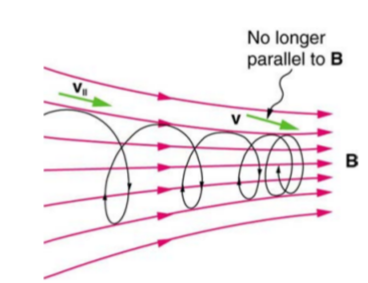
The angle θ is between the velocity and the magnetic field.

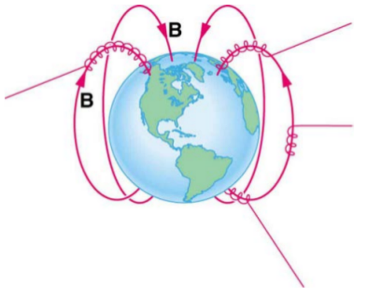
A cosmic ray proton moving toward the Earth at 3×10^6 m/s experiences a magnetic force of 2×10^{-17} N. What is the strength of the magnetic field of the Earth? (1 Gauss = 10^{-4} Tesla).

- A: 0.1 Gauss
- B: 0.6 Gauss
- C: 1 Gauss
- D: 6 Gauss

Figure 12: The aurora borealis, or northern lights.

A cool talk on the aurora borealis:
`https://youtu.be/czMh3BnHFHQ`





One un-explained piece: what does it mean for the electrons and protons to *high-five* the neutral oxygen and nitrogen atoms?

CONCLUSION

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ANSWERS

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- Both A and B
- 1 ms
- 3.3 μ C