Magnetism (3 weeks)

CHAPTER 29: Magnetic fields exert a force on ***moving*** charges.

CHAPTER 30: Moving charges (currents) ***create*** magnetic fields.

CHAPTERS 31, 32: *Changing* magnetic fields create *electric* fields. (Induction)

Magnetic fields

Text sections 29.1, 29.4

- Magnetic poles, forces, and fields
- Force on a moving charged particle
- Force on a current-carrying wire

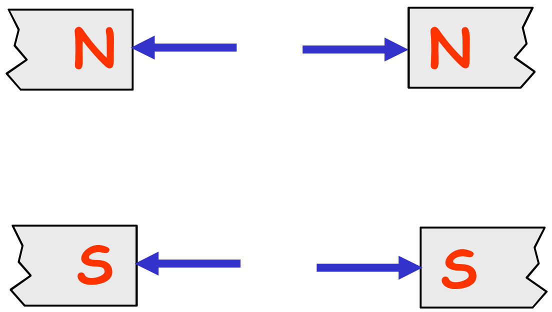
For practice:
Chapter 29, problems 1, 2, 5, 33, 35, 39

Magnets and Magnetic Forces

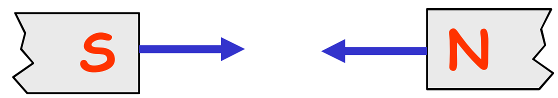
An early model, similar to electrostatics:
Each magnet has two **poles** *at its ends.*

Magnetic poles come in two types, "S" and "N".
Due to the Earth's magnetism, a magnet will tend to rotate until the "N" end points North.

Forces between magnets are due to the forces between each pair of poles, similar to the electrostatic forces between point charges.



like poles repel

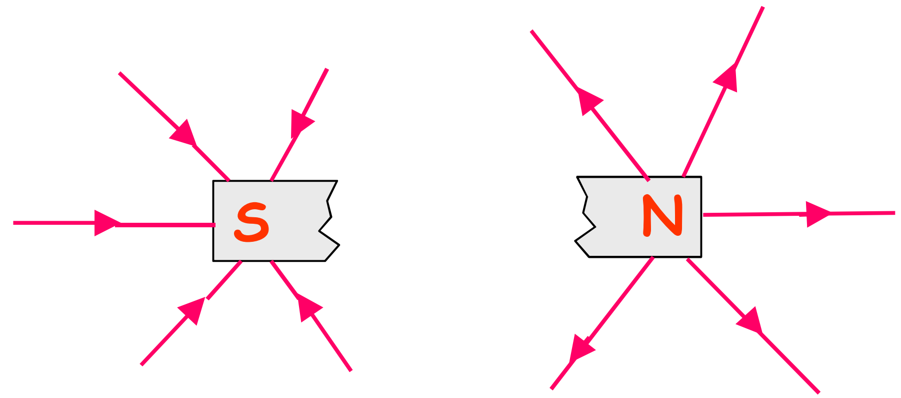


unlike poles attract

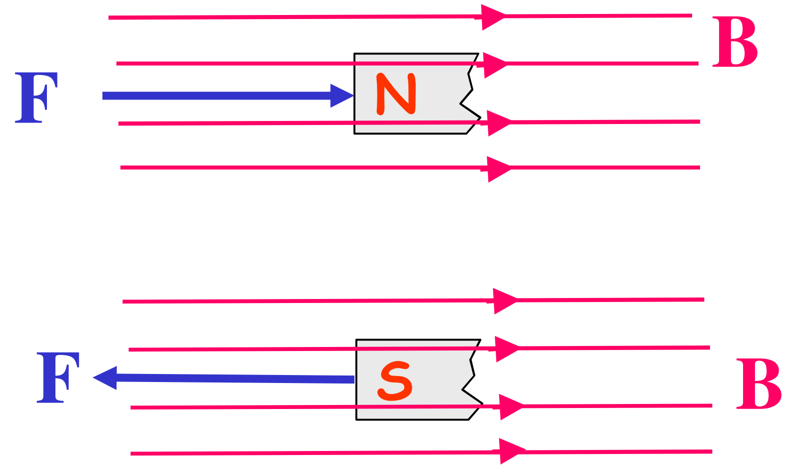
The force gets smaller as distance increases.

Magnetic Field **B**

Magnetic poles ***produce*** *a field* **B**

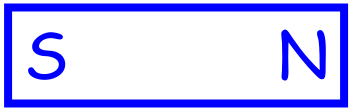


The field exerts forces on ***other*** *poles*

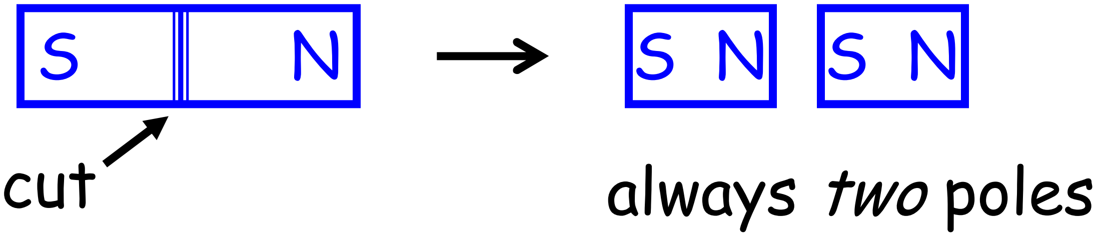


Magnetic Dipoles

2 poles, “N” and “S”, of equal strength.

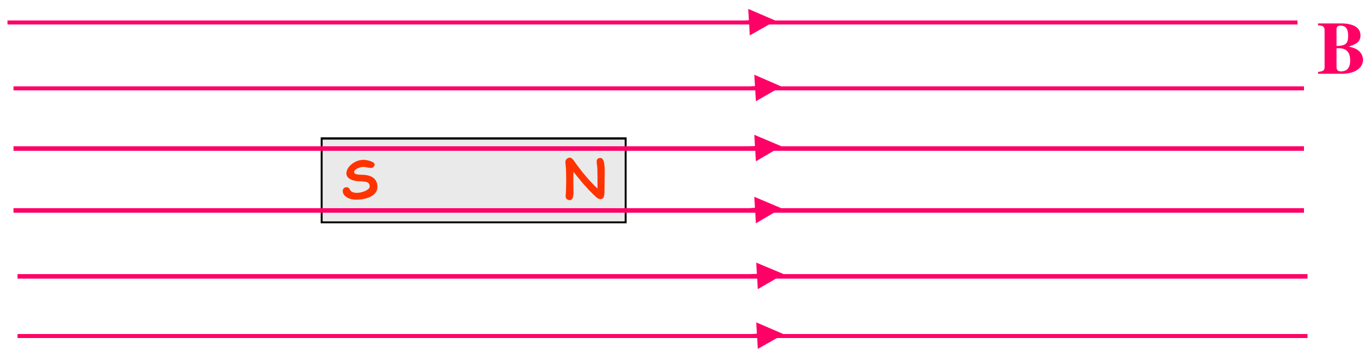


An isolated magnetic pole (monopole) has never been found. Real magnets seem to be made of dipoles.



Quiz

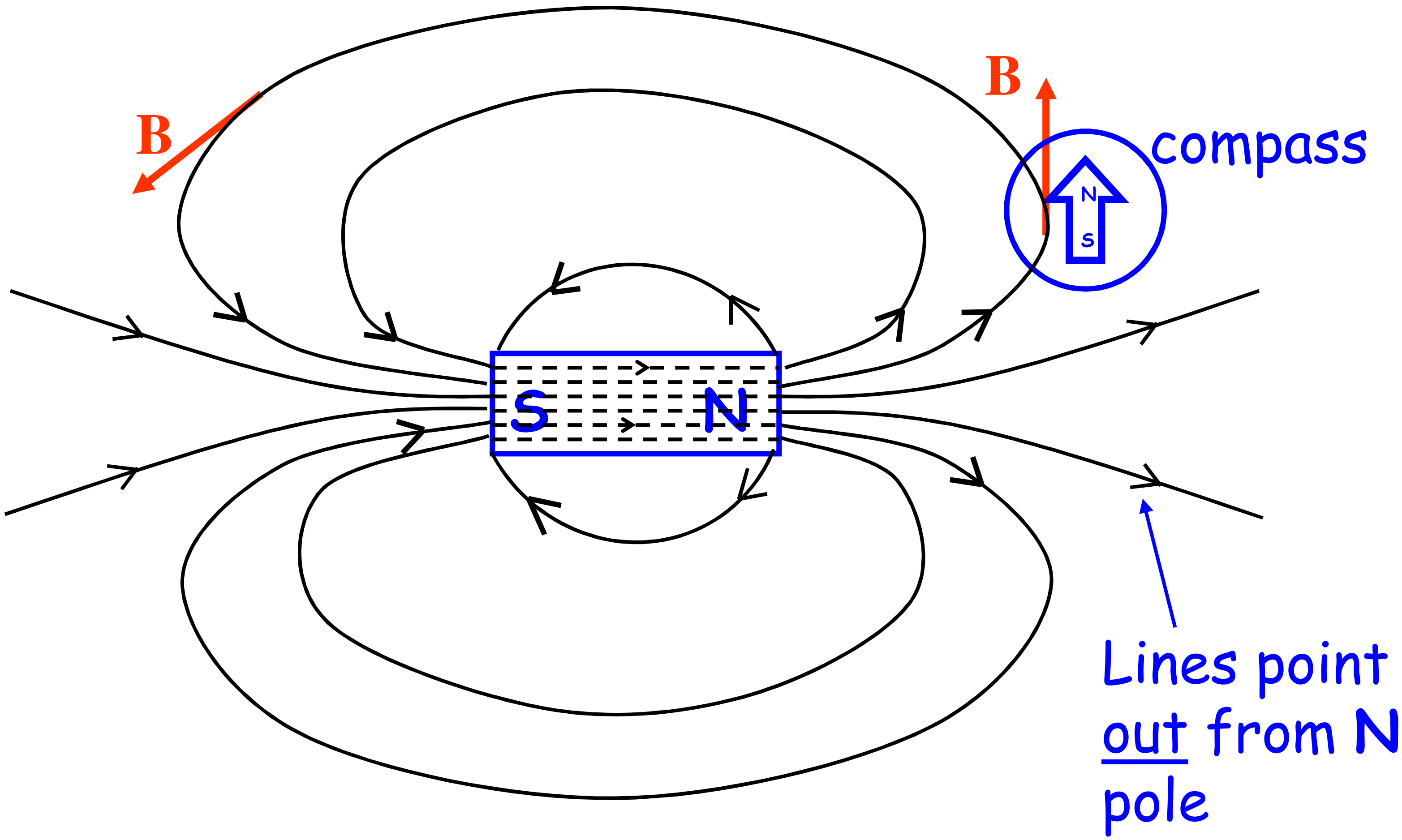
What is the direction of the force on a magnetic dipole placed in a uniform magnetic field?



A) $\rightarrow$ B) $\leftarrow$ C) $\uparrow$ D) $\downarrow$ E) zero

Fields and Dipoles

Compass needle (a magnetic dipole) aligns with **B**



Electric charge and Magnetic fields

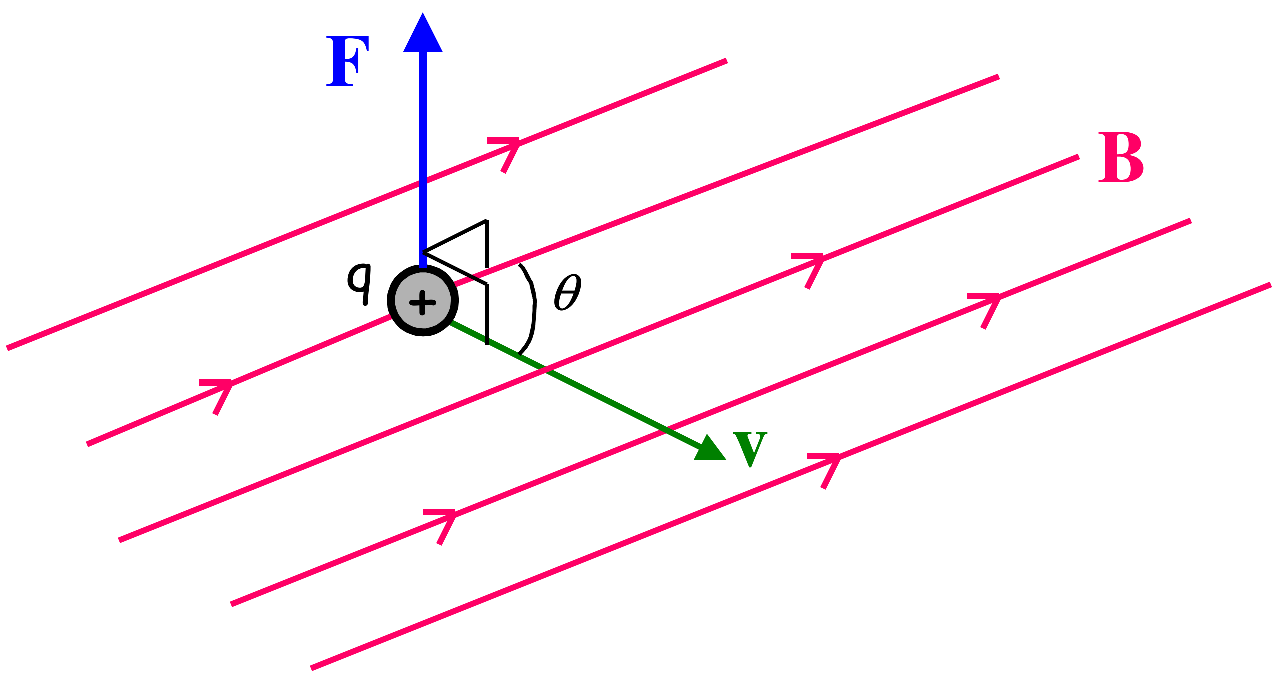
*Hans Ørsted discovered (1819) that **moving electric charges** create magnetic fields. Also, magnetic fields exert forces on **moving** electric charges.*

*A **current loop** acts like a magnetic dipole. We can build a complete model of magnetism from the properties of moving charges, without using the idea of "magnetic poles" at all.*

Define **B** by the force on a moving charge:

Charge q with velocity $\vec{v}$, feels a force

$$\vec{F} = q\vec{v} \times \vec{B}$$ (vector product)



$$\vec{F} = q\vec{v} \times \vec{B}$$

1) $\vec{F} \perp \vec{B}$

2) $\vec{F} \perp \vec{v}$ ➔ NO work done!

3) $|\vec{F}| = q\,v\,B\sin\theta$

4) For a negative charge, the force is in the *opposite* direction.

UNITS: $\dfrac{N}{C \cdot m/s} = \text{tesla}\,(T) = \dfrac{\text{weber}}{m^2} \left(\dfrac{Wb}{m^2}\right)$

Also... 1 gauss (G) = 10^{-4} T

Typical Fields

Earth's Field	~ 1 x 10^{-4} T (1 gauss)
Strong fridge magnet	~ 10^{-2} T (100 G)
Big lab electromagnet	~ 4 T (40,000 G)
Superconducting magnet	up to ~ 20 T (200,000 G)

Vector Diagrams

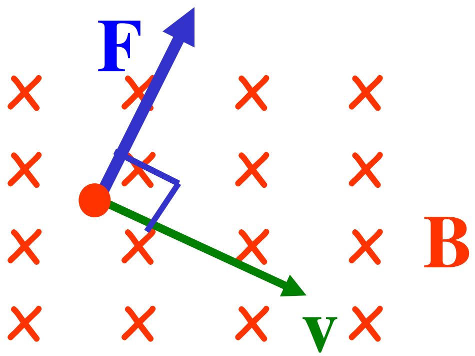
The three vectors **F**, **v**, **B** *never lie in a single plane, so the diagrams are always three-dimensional. The following convention helps with drawing the vectors.*

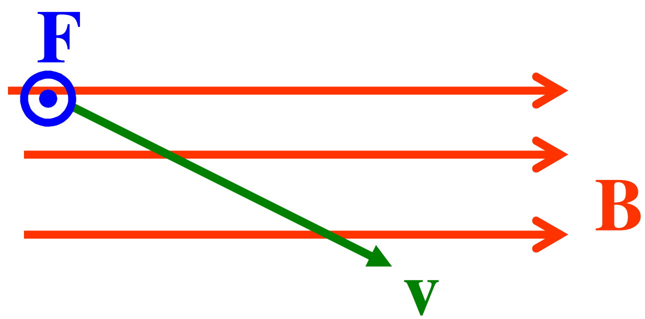
For vectors perpendicular to the page, we use:

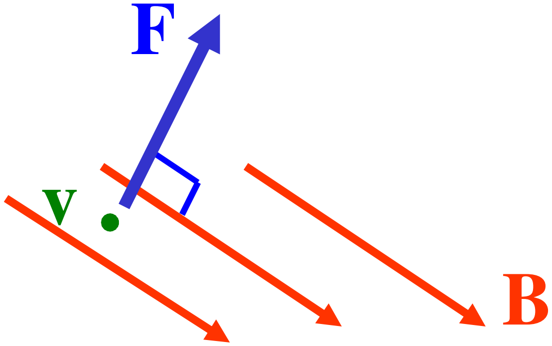
- X into the page (tailfeathers of arrow)
- • out of the page (point of arrow)

Examples

For a positive charge q: draw the force vector.





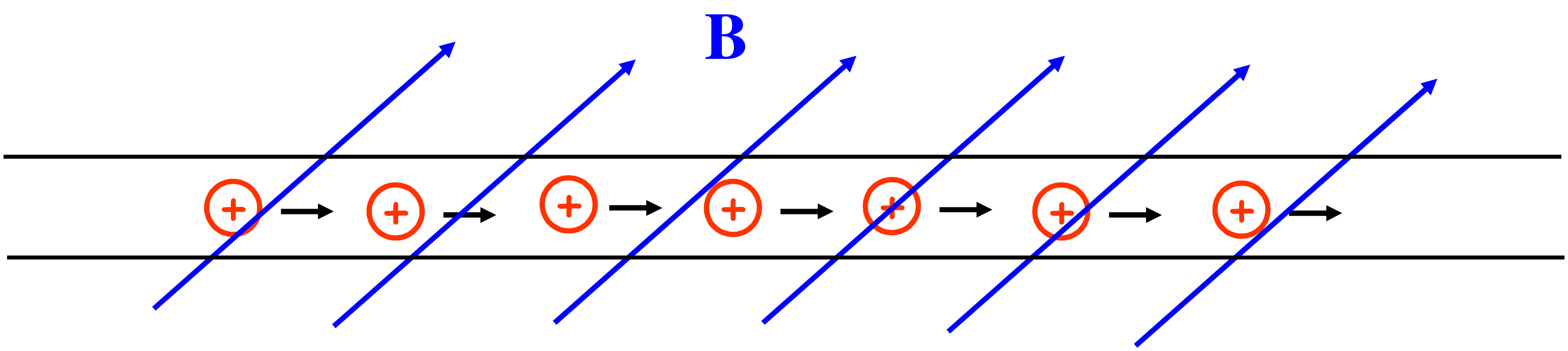


Quiz

An electron is moving from left to right across the screen. The "N" end of a bar magnet is brought towards the electron from behind the screen. In which direction will the electron deflect?

A) → **B)** ← **C)** ↑ **D)** ↓ **E)** no deflection

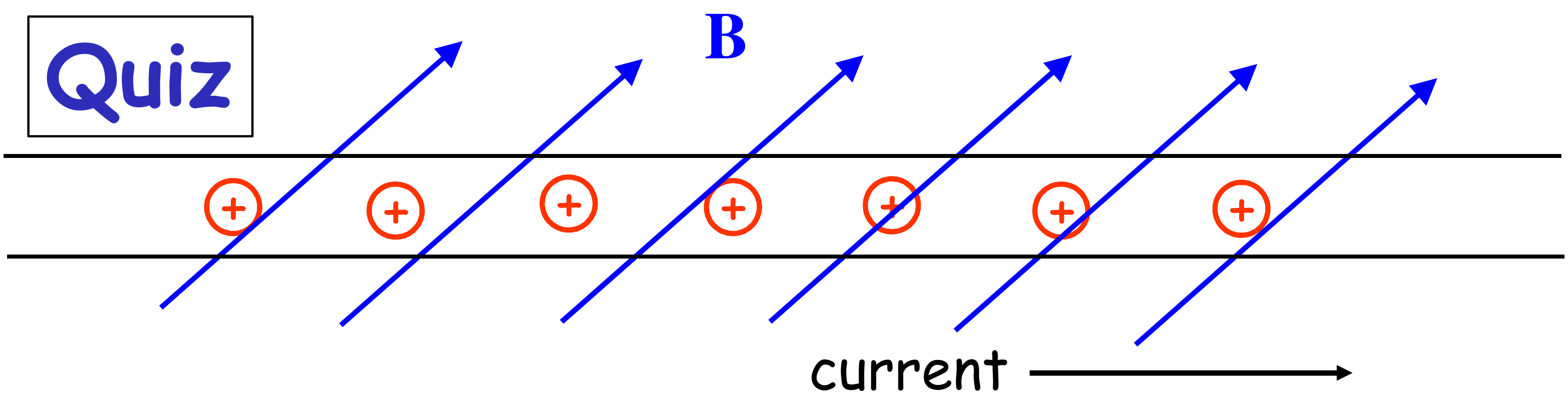
Force on a Current-Carrying Wire



Uniform external field **B**, straight wire of length L;
charges q moving at velocity **v**.

Each individual charge feels a force $\mathbf{F}_1 = q\mathbf{v} \times \mathbf{B}$

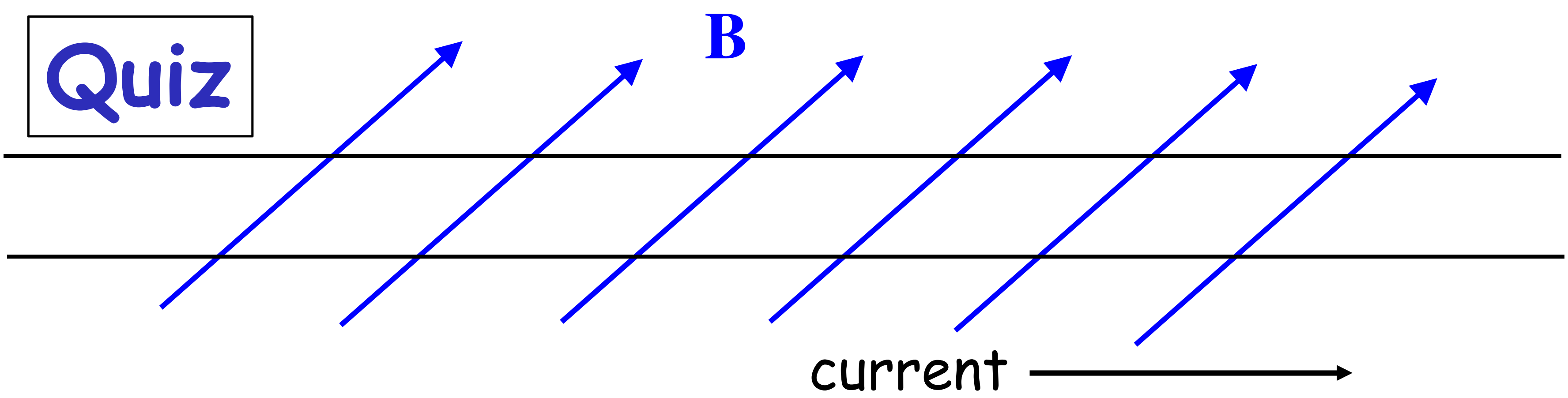
Quiz



Current *I* flows from left to right. In what direction is the force on the wire?

A) up
B) down
C) into the page
D) out of the page
E) at an angle to the vertical on the page

Quiz



The current and field are the same as in the previous example, but the mobile charge carriers are *negative.* The force on the wire is

A) in the same direction as with positive charge carriers
B) in the opposite direction