Wednesday March 22, 2017

Last time:

- Introduction to magnetism
- Electric force vs magnetic force on charges
- Vector cross product
- Consequences of magnetic force
- Motion of charges in magnetic fields
- Cyclotron motion, cyclotron frequency, q/m
- Mass spectrometers

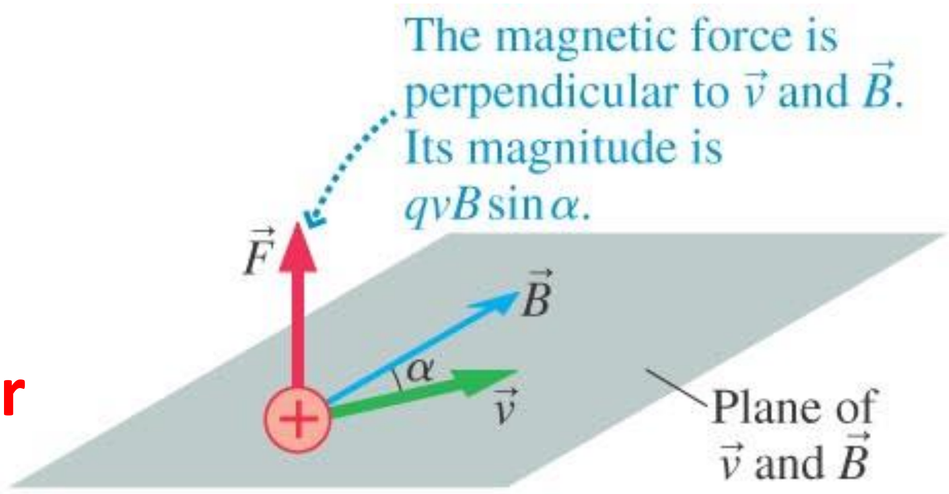
Today:

- Charges on helical paths in B-field (aurora)
- The Hall Effect: underpinning of a B-field probe
- Velocity selector via crossed E- and B-fields
- Bainbridge Mass Spectrometer

Magnetic Force on Charges

Magnetic force acts only on a moving charge.

It is perpendicular to both B and v.



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

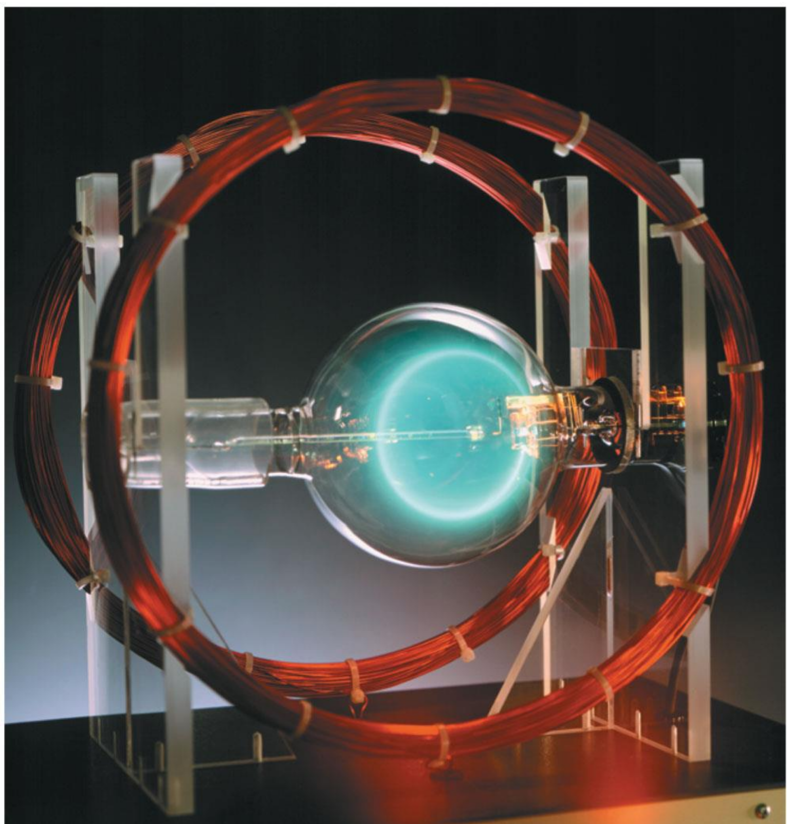
Magnitude: $F_B = qvB\sin\alpha$

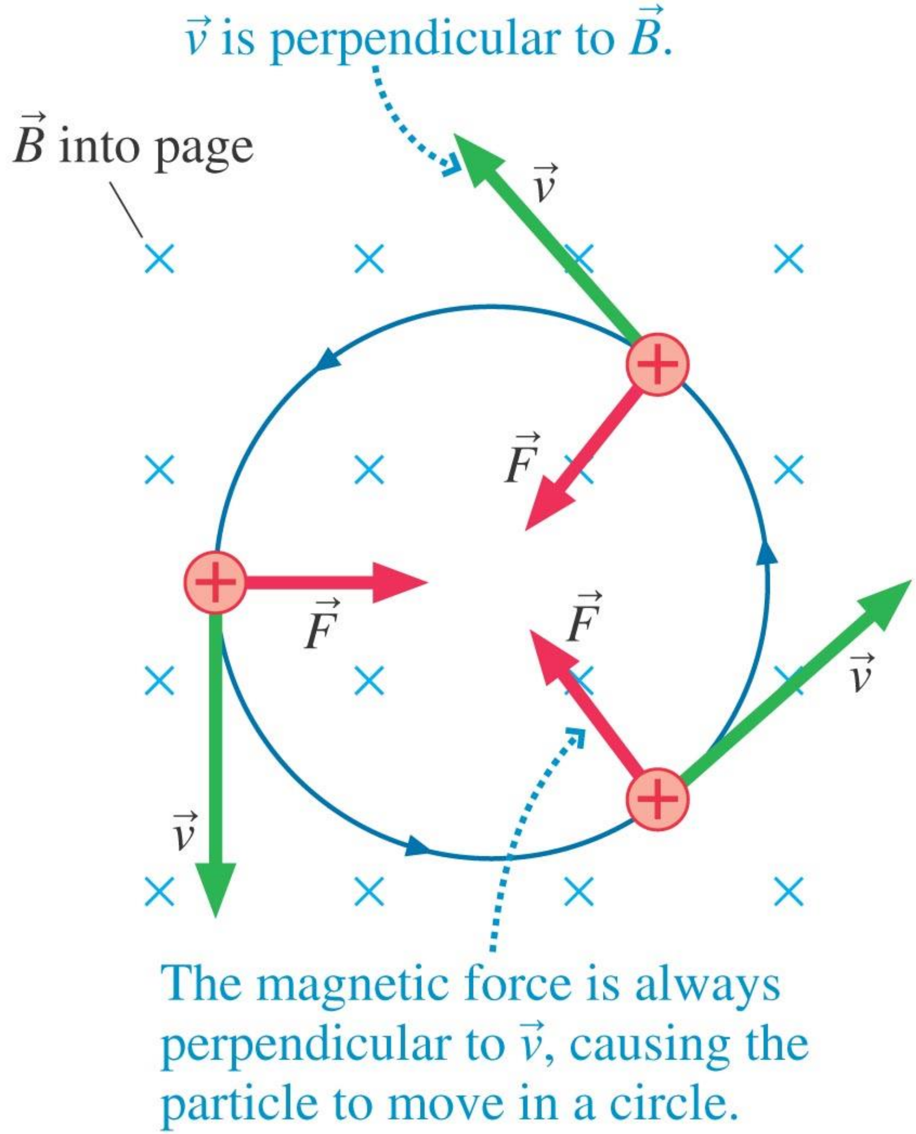
Direction: RH rule

Cyclotron Motion

$$\left|\vec{F}_B\right| = |q|\cancel{v}B = m\frac{v^{\cancel{2}}}{R}$$

$$\boxed{R = \frac{mv}{|q|B}}$$



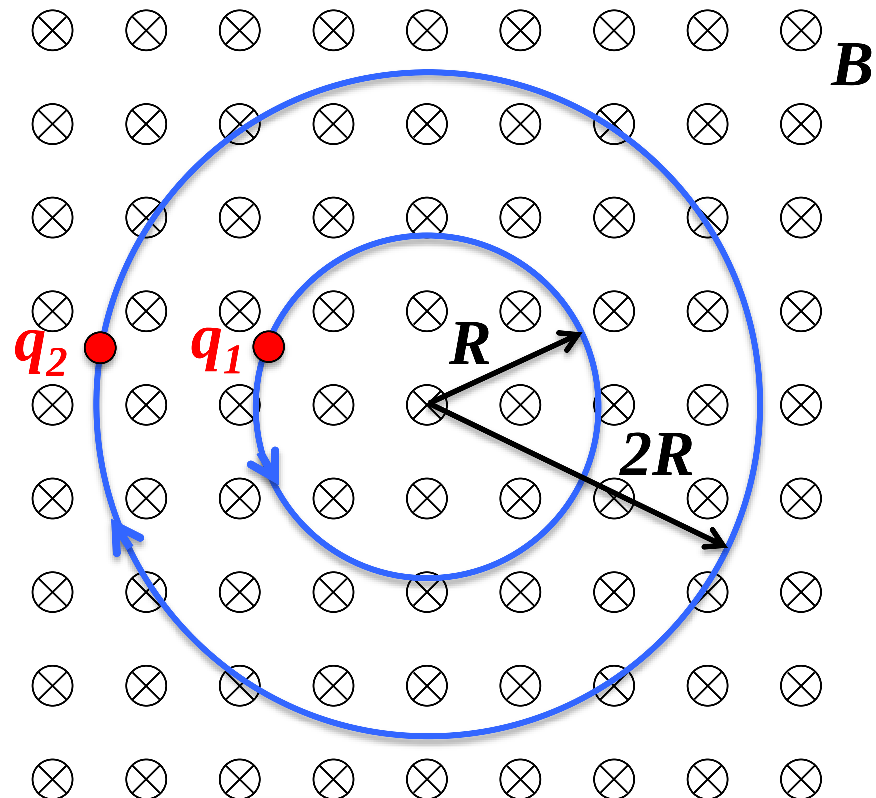


Top Hat Question

Top Hat Question

Two charges q_1 and q_2 with the same mass m and the same magnitude of charge $|q|$ are undergoing cyclotron motion in a uniform B-field.

What are the **signs of the charges**?



A. Both positive

B. Both negative

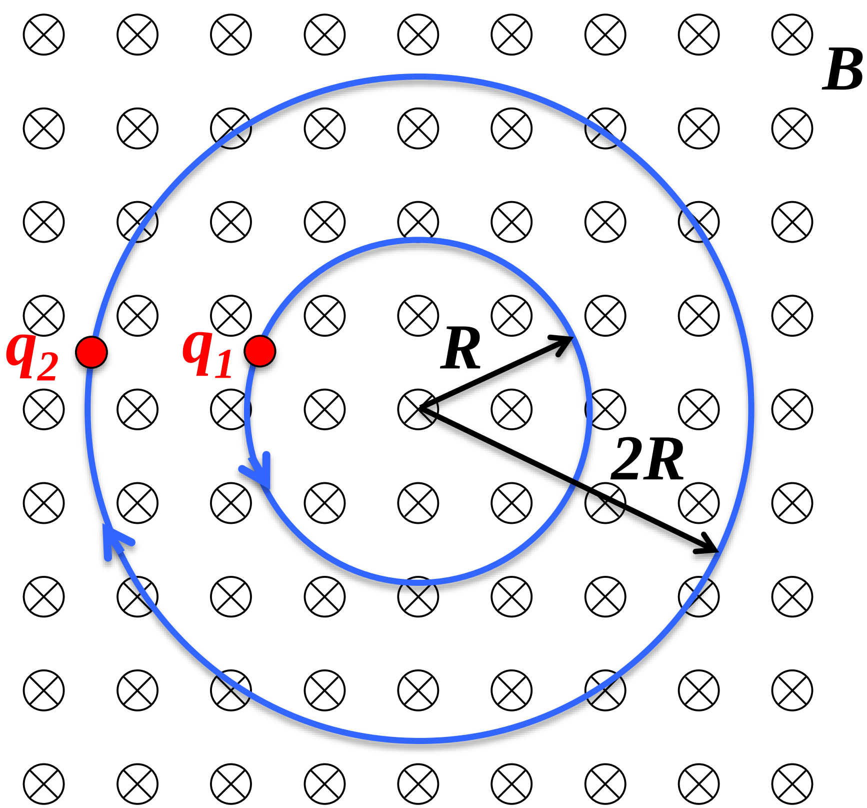
C. q_1 positive, q_2 negative

D. q_1 negative, q_2 positive

Top Hat Question

Two charges q_1 and q_2 with the same mass m and the same magnitude of charge $|q|$ are undergoing cyclotron motion in a uniform B-field.

If the speed of q_1 is v, what is the speed of q_2?



A. v

B. $2v$

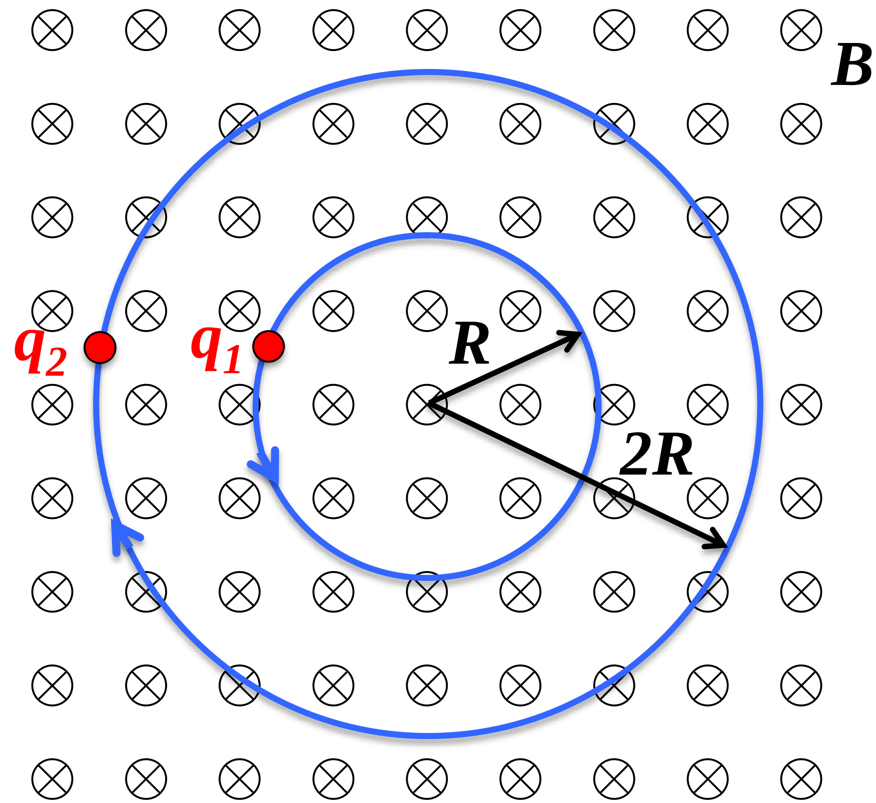
C. ½ v

D. $4v$

Top Hat Question

Two charges q_1 and q_2 with the same mass m and the same magnitude of charge $|q|$ are undergoing cyclotron motion in a uniform B-field.

If the period of rotation of q_1 is T, what is the period of rotation of q_2?



A. T

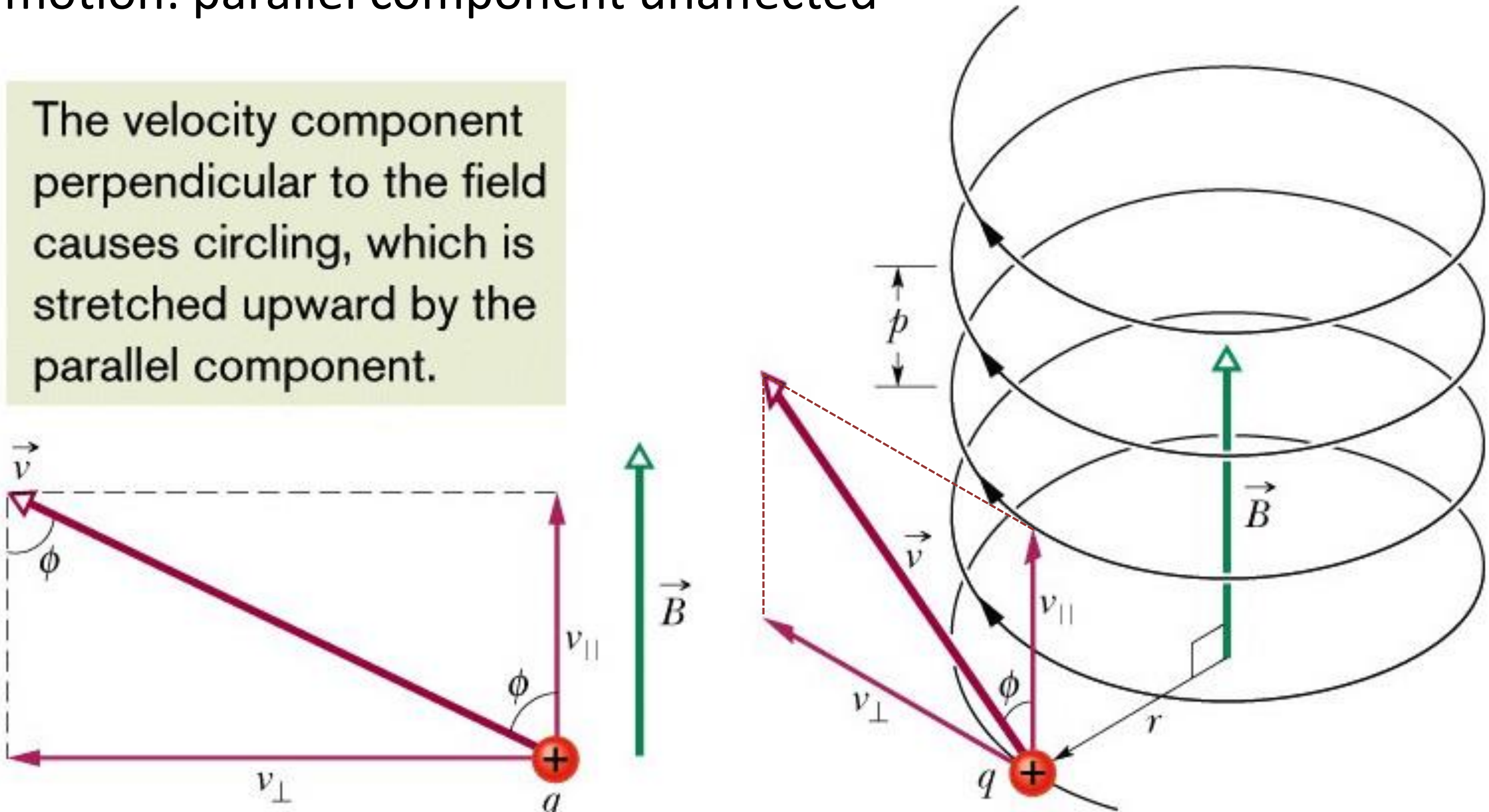
B. $2T$

C. $\frac{1}{2}T$

D. $4T$

Helical Paths Through a B-field

Splitting up the velocity into a component parallel to B-field and a component perpendicular to B-field immediately leads to helical motion: parallel component unaffected

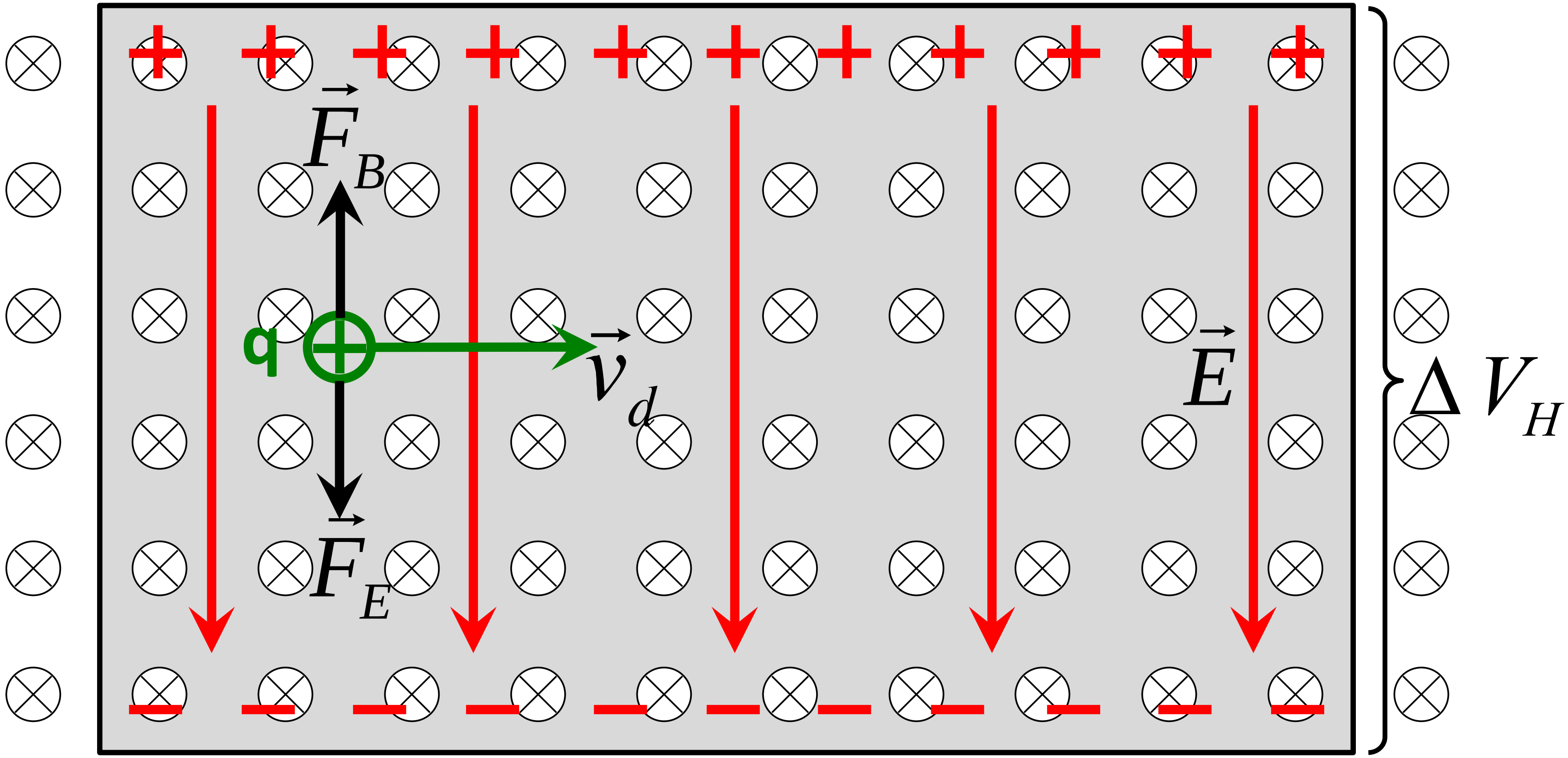


Helical Paths: document camera

We can analyze and specify the motion exactly as the charge moves in a helix.

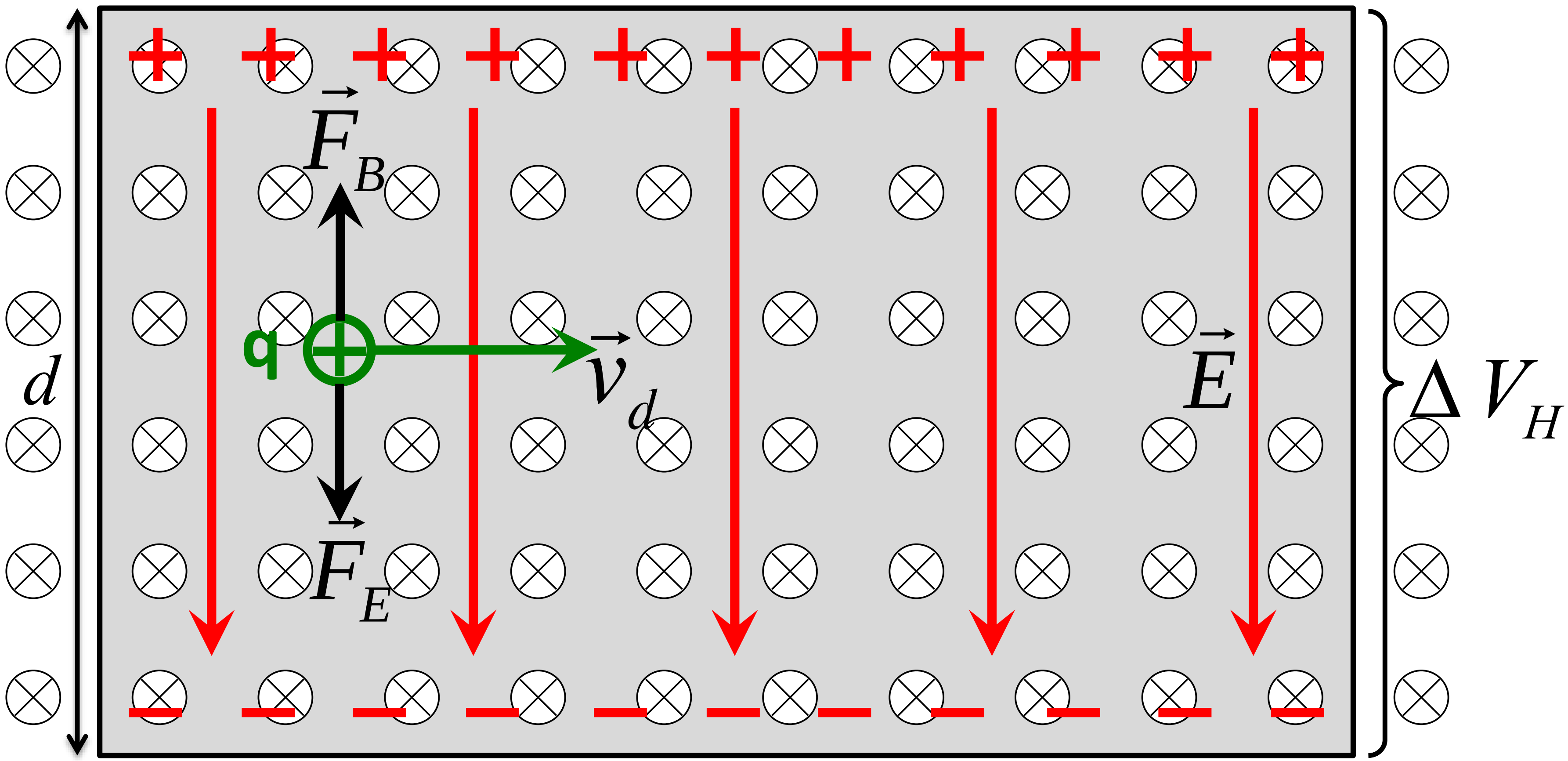
The Hall Effect

Due to the B-field, net charge build up on the edges.



In equilibrium, current still flows. Need to balance the magnetic and electric forces on the charge carriers.

The Hall Effect

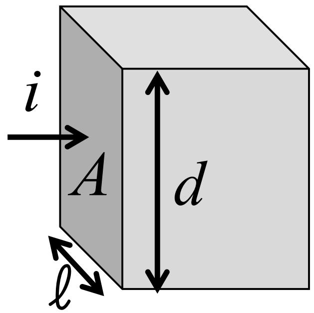


$$F_B = q v_d B \qquad F_E = q\frac{\Delta V_H}{d} \qquad q\frac{\Delta V_H}{d} = q v_d B \qquad \boxed{\Delta V_H = v_d B d}$$

The Hall Effect

We have just found that the voltage established across a conductor carrying a current in a magnetic field is

$$\Delta V_H = v_d B d$$



We previously related the drift speed to the current via

$$v_d = \frac{i}{neA}$$

where $A = \ell d$ and n is a material property

We can then relate the Hall voltage to known quantities:

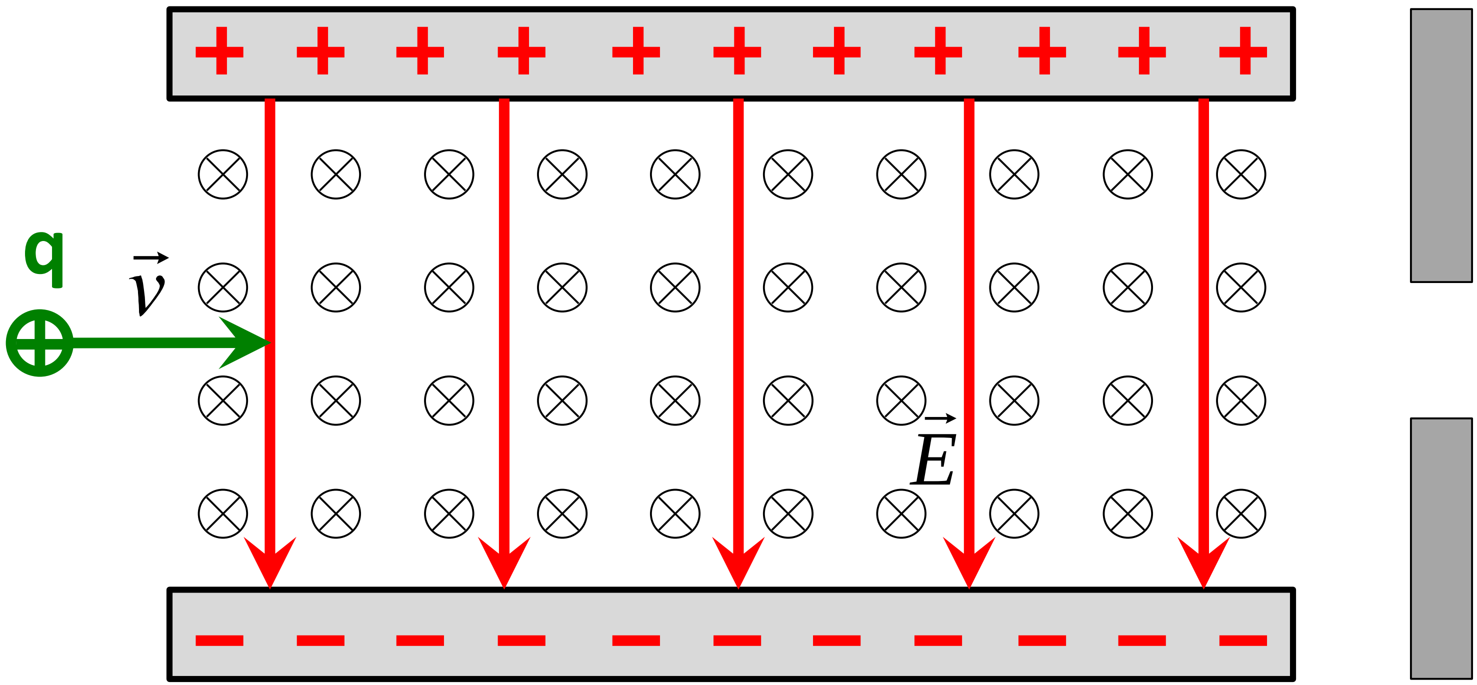
$$\Delta V_H = \frac{i}{ne\ell \cancel{d}} B\cancel{d} = \frac{iB}{ne\ell}$$

In practical applications, you measure ΔV_H to find B:

$$\boxed{B = \frac{ne\ell}{i}\Delta V_H}$$

How the B-field probe used in the next lab works

Similar concept: velocity selector

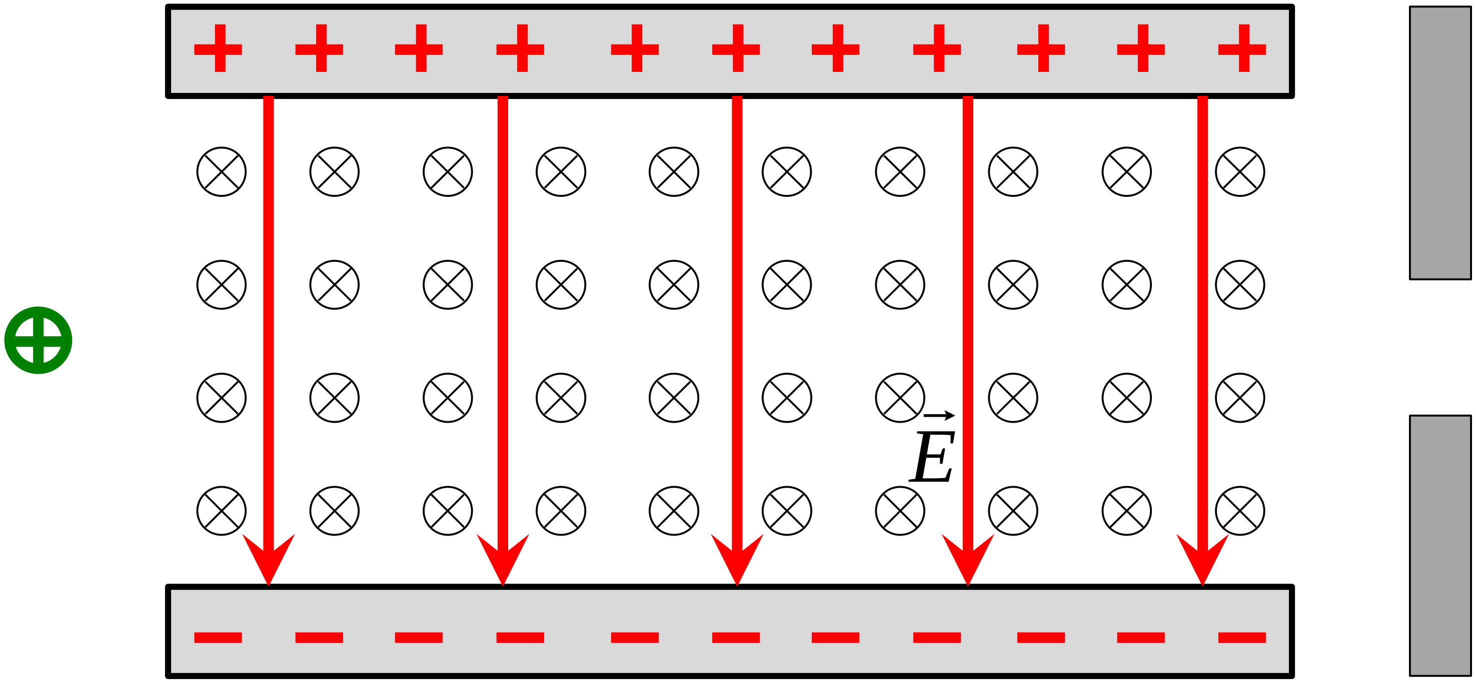


In a velocity selector, you send a charge through a region with crossed E and B fields, which leads to electric and magnetic forces:

$$\vec{F}_e = q\vec{E} \qquad \vec{F}_B = q\vec{v} \times \vec{B} \qquad qE = qvB \qquad v = \frac{E}{B}$$

If the forces balance ($F_{net} = 0$) the charge makes it through the slit

Similar concept: velocity selector



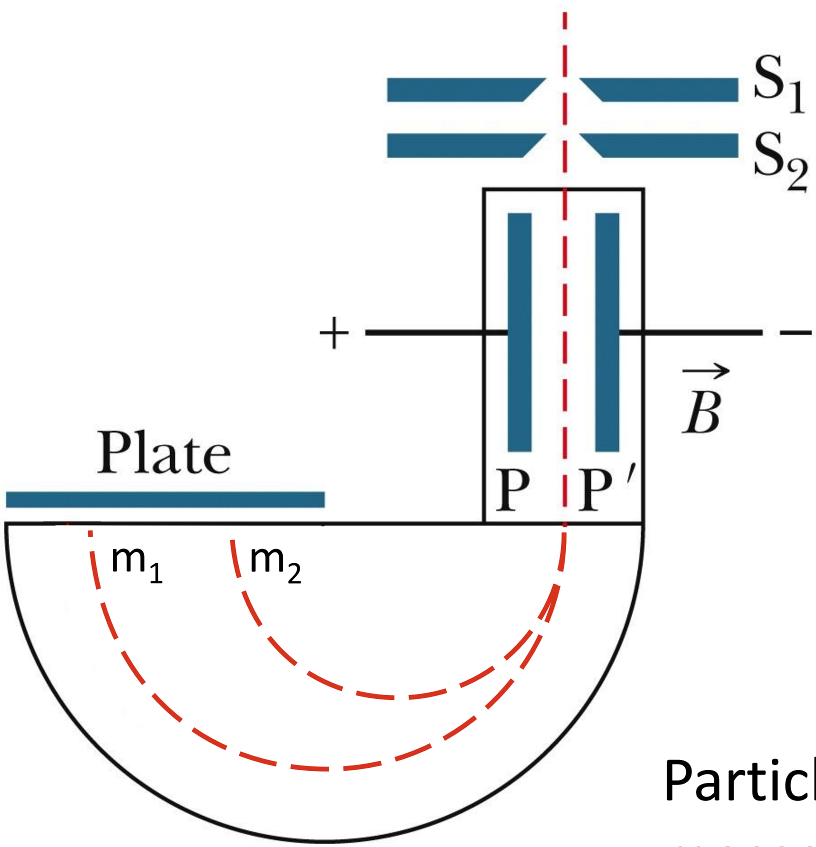
If the forces don't balance the charge hits the wall

$$qE - qvB = ma$$

We pick the E and B magnitudes to select the speeds we want

Bainbridge Mass Spectrometer

Accelerate charges through ΔV so they all have same Kinetic Energy



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The slits S_1 and S_2 ensure the beam of particles is collimated.

The beam enters a region of crossed E and B-fields

A narrow slit ensures only particles with a specific speed enter

Particles with same KE but different masses and charges will have different radius in B field

Wednesday March 22, 2017 – lecture 2

Last time:

- Charges on helical paths in B-field (aurora)
- The Hall Effect: underpinning of a B-field probe
- Velocity selector via crossed E- and B-fields
- Bainbridge Mass Spectrometer

Today:

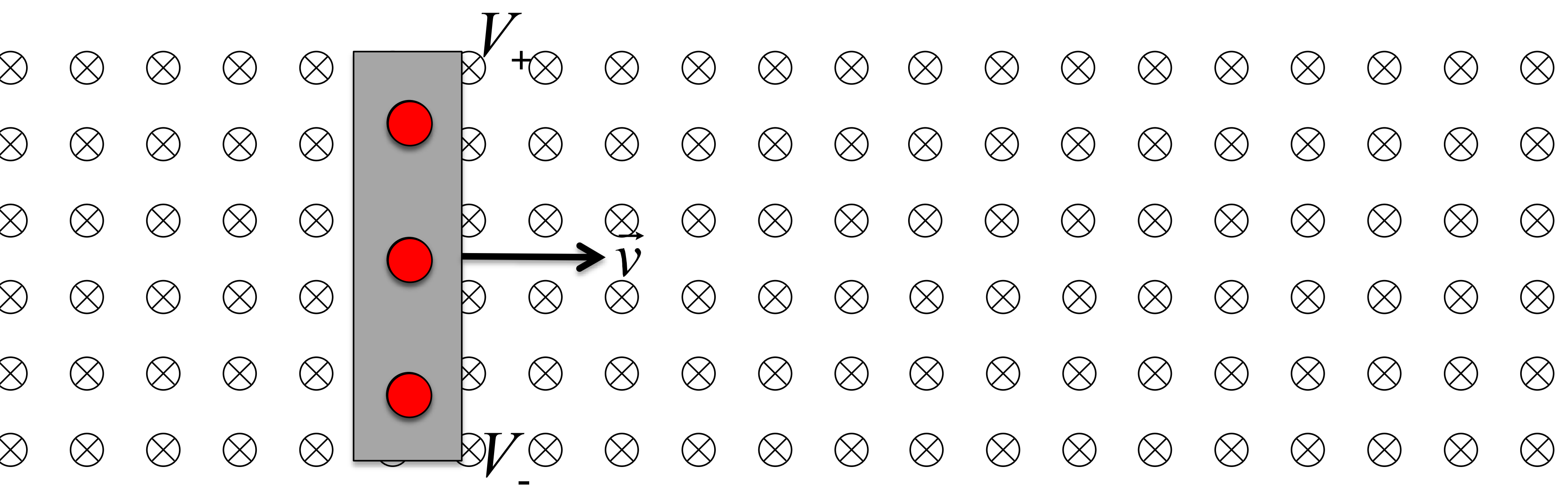
- Conductors moving through B-fields: Hall(ish) Effect
- Magnetic force on current carrying wires
- Torque on a current loop

Conductors moving in B-fields

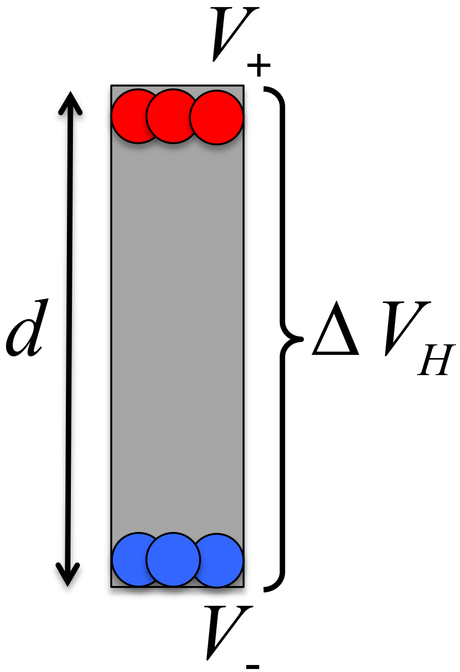
We've seen that free charges moving in a B-field feel a force perpendicular to the field and the charge's velocity:

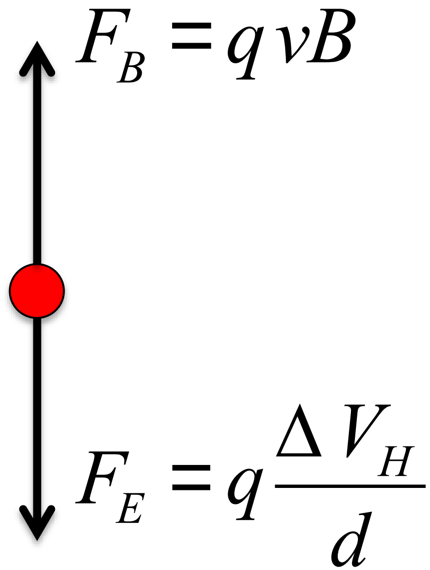
$$\vec{F}_B = q\vec{v} \times \vec{B}$$

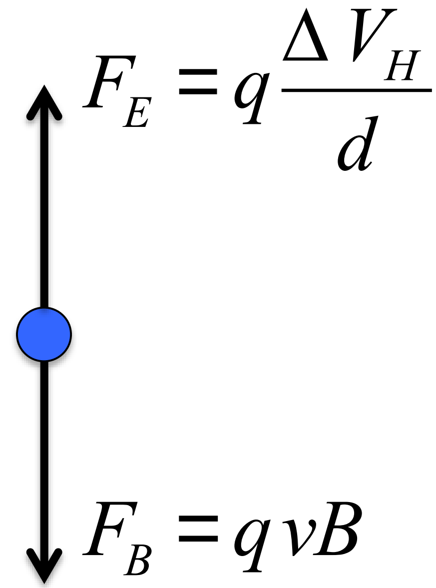
Conductors are full of charges that are free to move around (yet they have to stay confined to the conductor itself). If a conductor moves in a magnetic field, these charges also feel a magnetic force



Conductors moving in B-fields







In equilibrium, forces balance, leading to a constant voltage

$$q \frac{\Delta V_H}{d} = qvB$$

$$\boxed{\Delta V_H = vBd}$$

Forces on Current-Carrying Wires

Current in wires is nothing more than charges in motion. It doesn't matter if we consider $-q$ moving opposite i or $+q$ moving in the same direction as i

In a magnetic field, these charges feel a force and get deflected from their normal straight path. For a single charge:

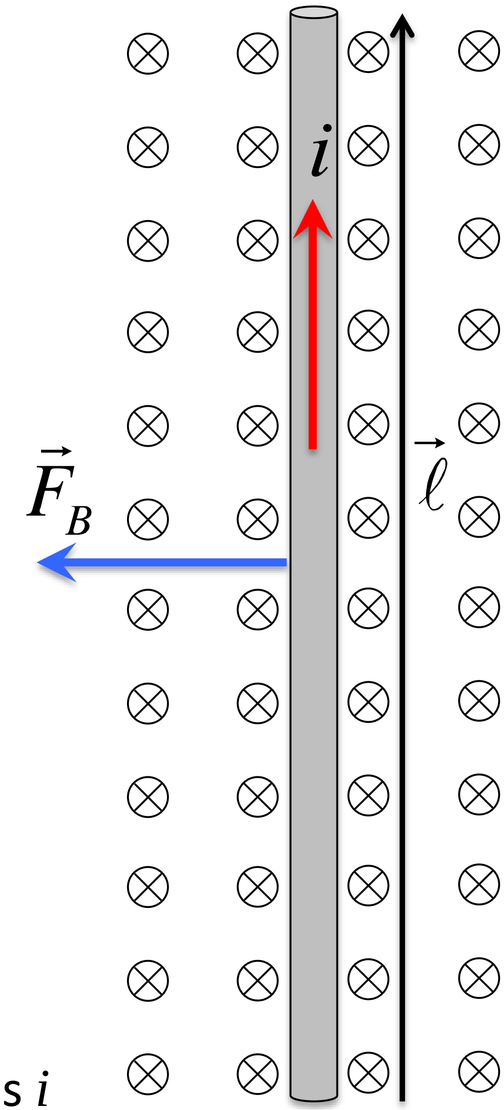
$$\vec{F}_B = q\vec{v}_d \times \vec{B}$$

For N charges moving through the wire:

$$Nq\vec{v}_d = \left(nAq\vec{v}_d\right)\ell = i\vec{\ell}$$

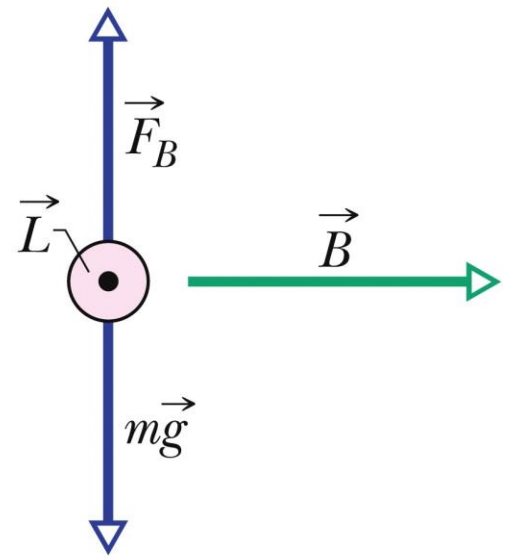
$$\boxed{\vec{F}_B = i\vec{\ell} \times \vec{B}}$$

Length of wire, direction same as i



TopHat Question

A wire of length 50 cm is carrying a current i out of the page and is sitting in a uniform magnetic field of 500 mT pointing to the right. If the wire has a mass of 25 g, what current i is needed to support its weight?



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$$\vec{F}_B = i\vec{\ell} \times \vec{B}$$

A. $9.81\text{x}10^{-3}$ A

B. 1.02 A

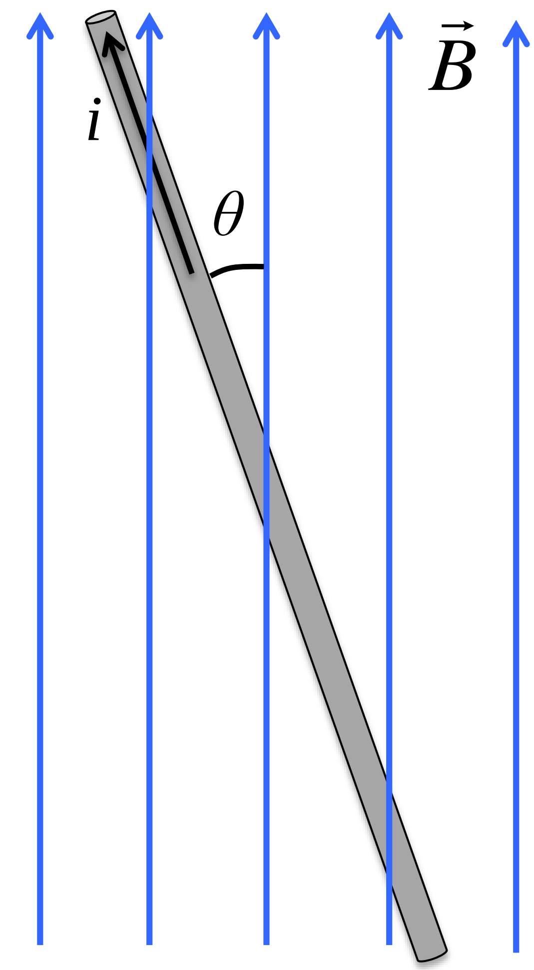
C. 0.981 A

D. $1.02\text{x}10^{-3}$

TopHat Question

A wire of length 50 cm is carrying a current i and is sitting in a uniform magnetic field B as shown. What is the magnitude and direction of the magnetic force on the wire?

$$\vec{F}_B = i\vec{\ell} \times \vec{B}$$



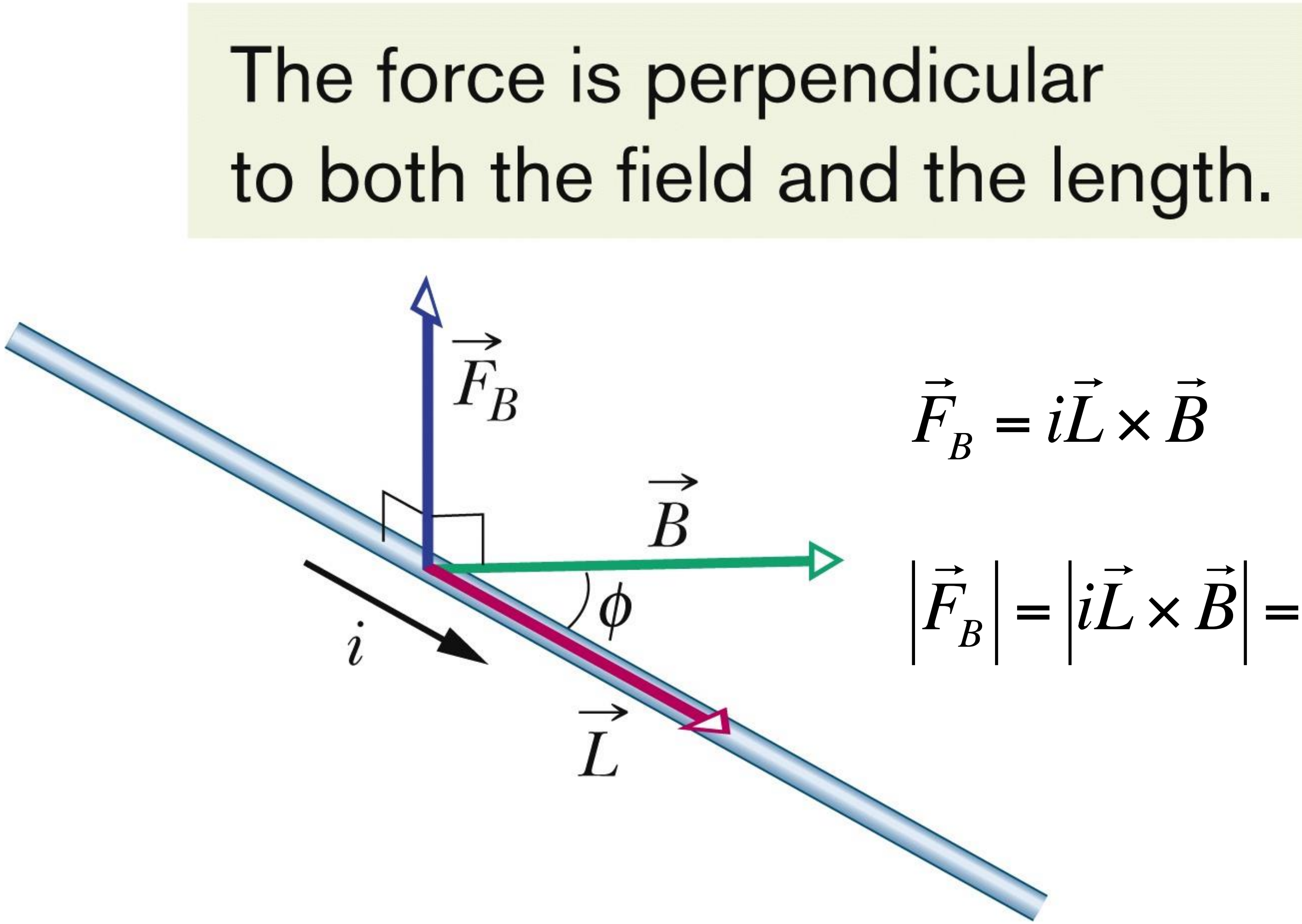
A. ilB $\odot$

B. $ilB\sin\theta$ $\otimes$

C. $ilB\sin\theta$ $\swarrow$

D. ilB $\nearrow$

Forces on Current-Carrying Wires: B and L not perpendicular



$$\vec{F}_B = i\vec{L} \times \vec{B}$$

$$\left|\vec{F}_B\right| = \left|i\vec{L} \times \vec{B}\right| = iLB\sin\phi$$

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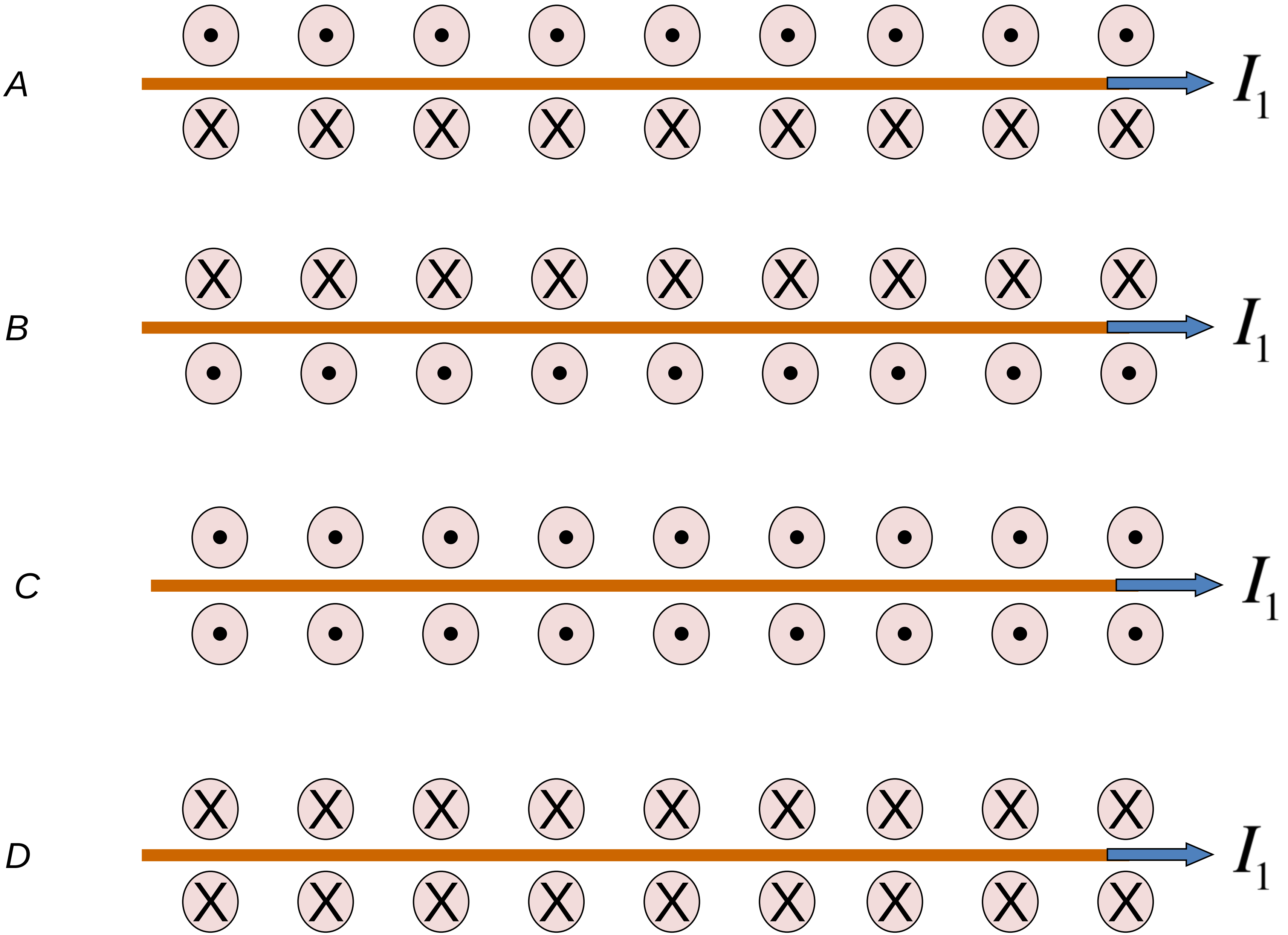
Force Between Two Parallel Wires

Derive an expression for the magnetic force on wire #2 due to the magnetic field created by the current flowing in wire #1.

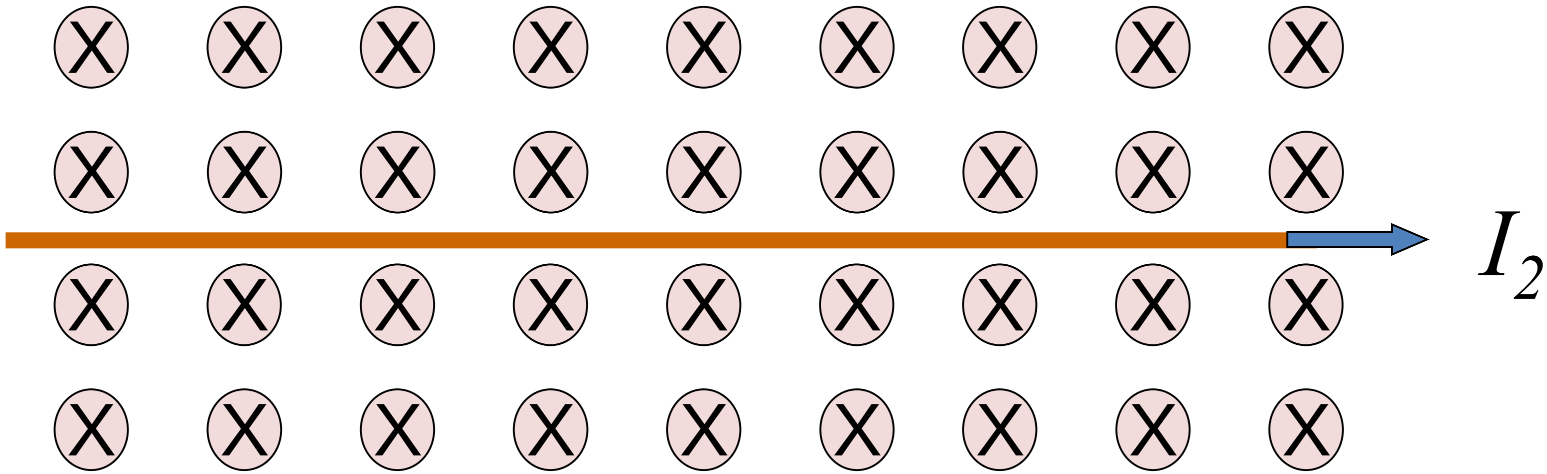
Top Hat Question

Which figure correctly represents magnetic field created by I_1 flowing in upper wire?

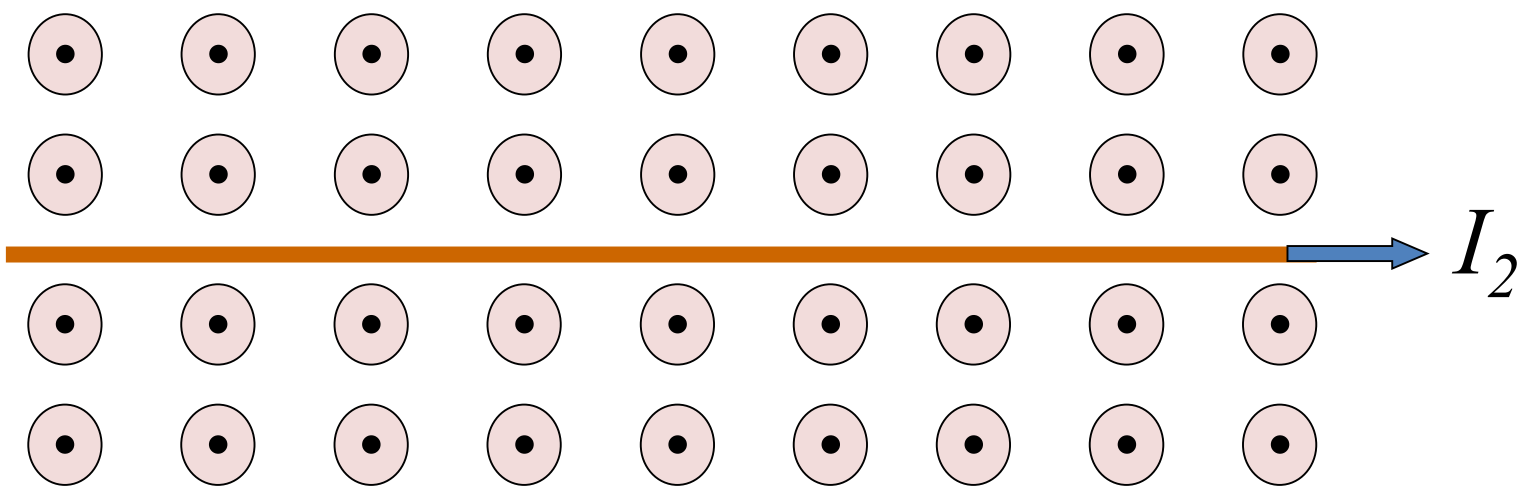


Which figure correctly represents magnetic field in which the lower wire is immersed?

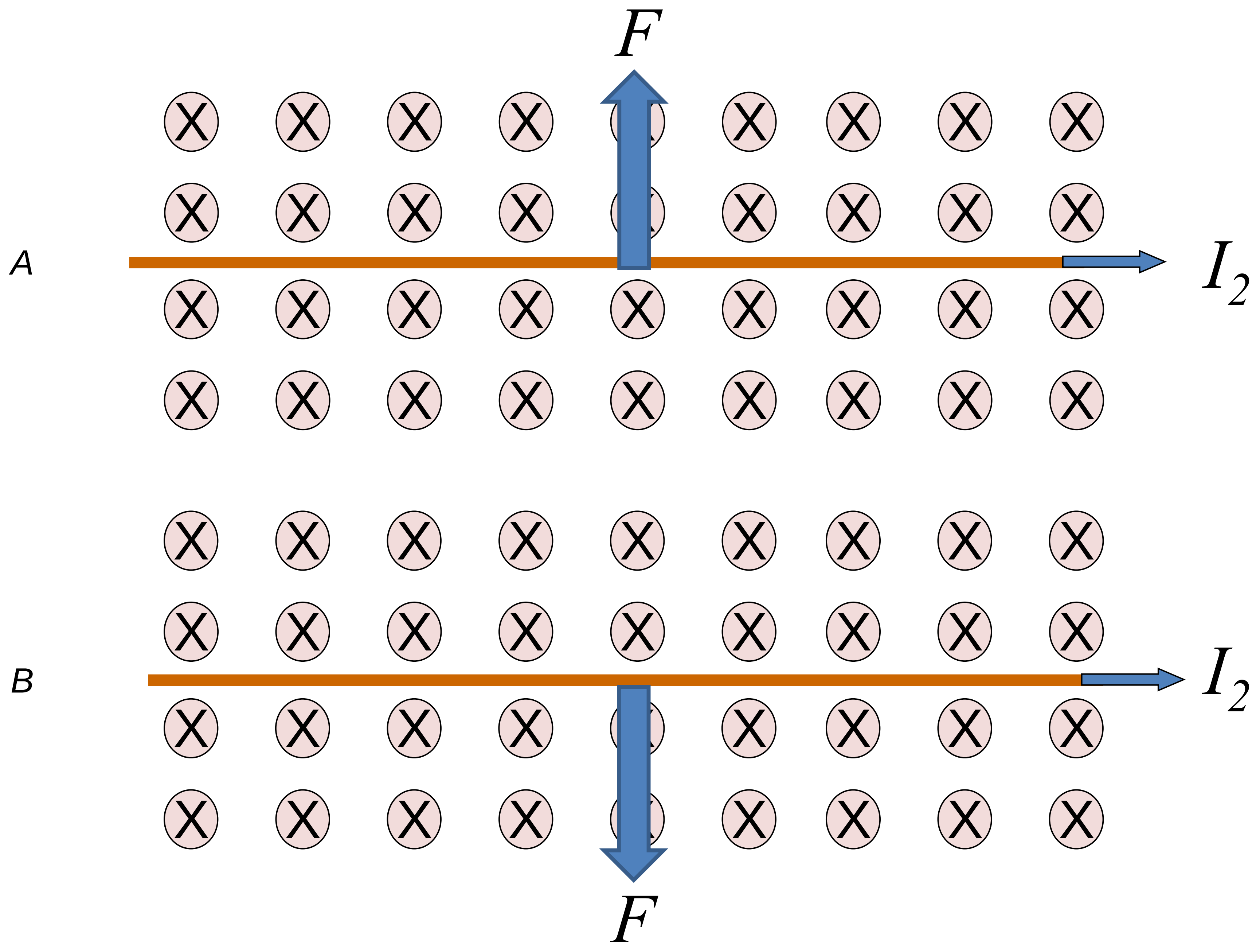
A



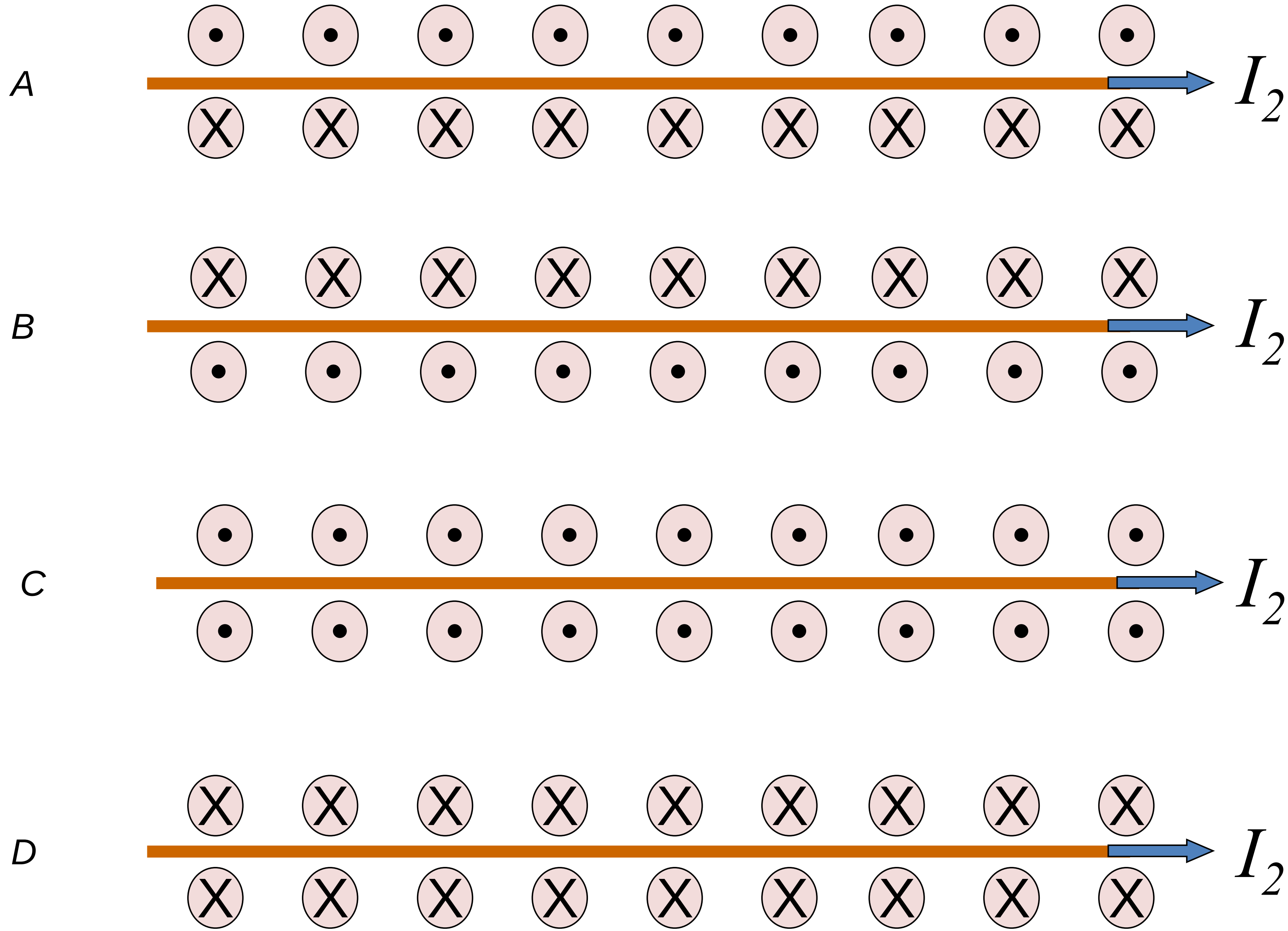
B



Which figure correctly represents **force** on the **lower wire**?

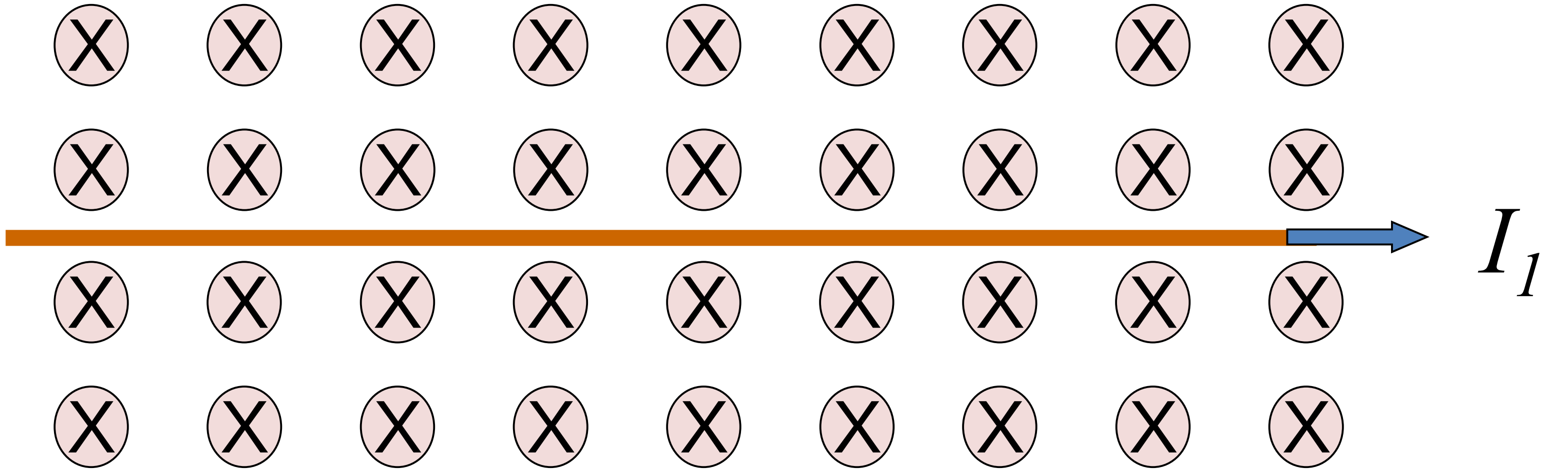


Which figure correctly represents magnetic field created by I_2 flowing in lower wire?

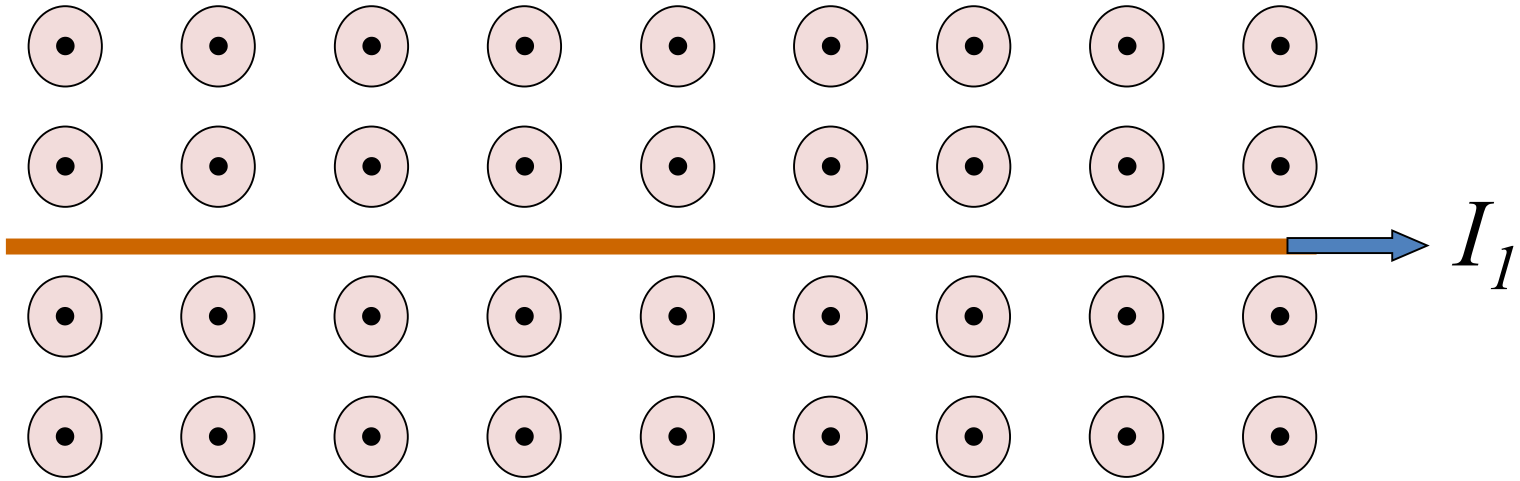


Which figure correctly represents **magnetic field** in which **upper wire** is immersed?

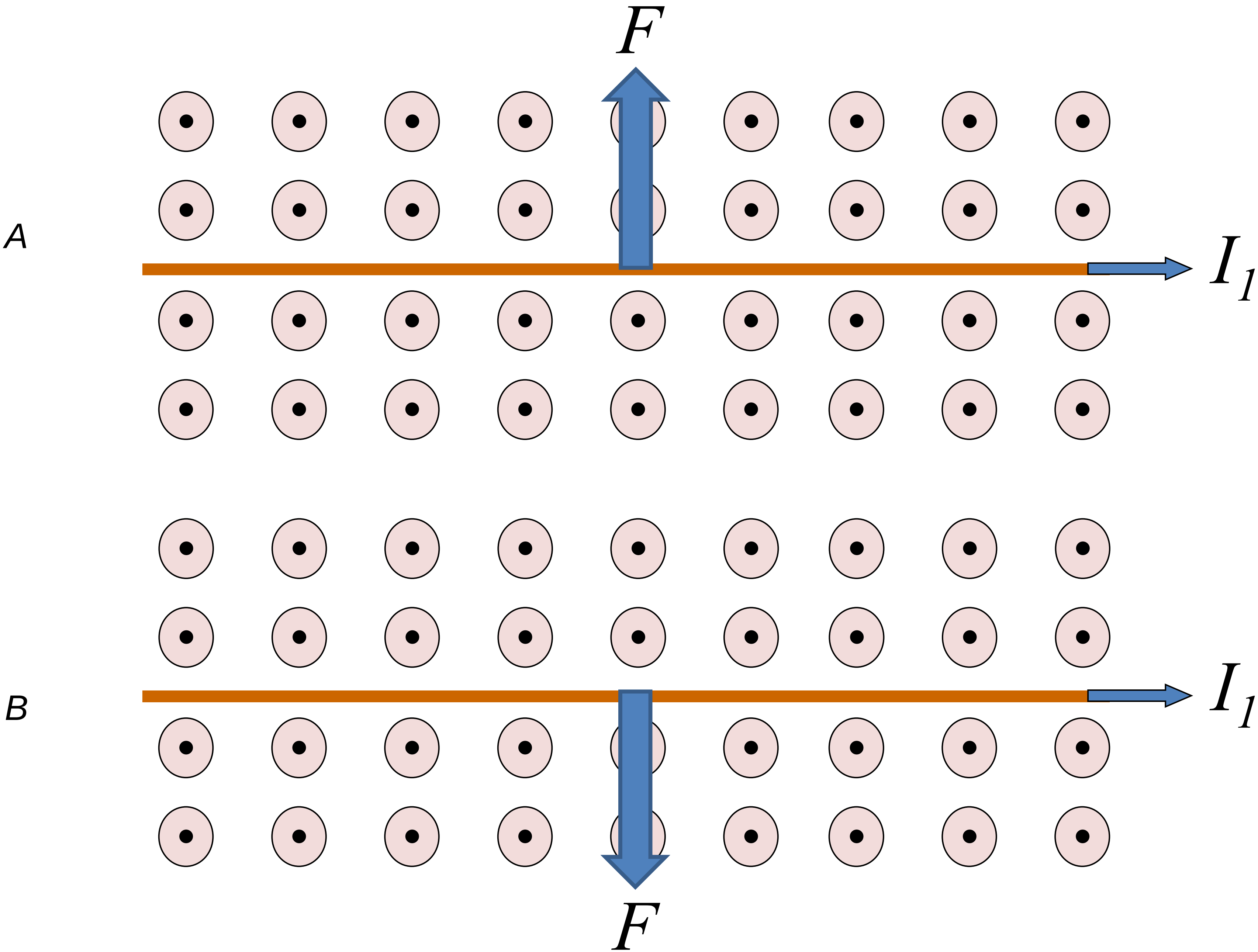
A



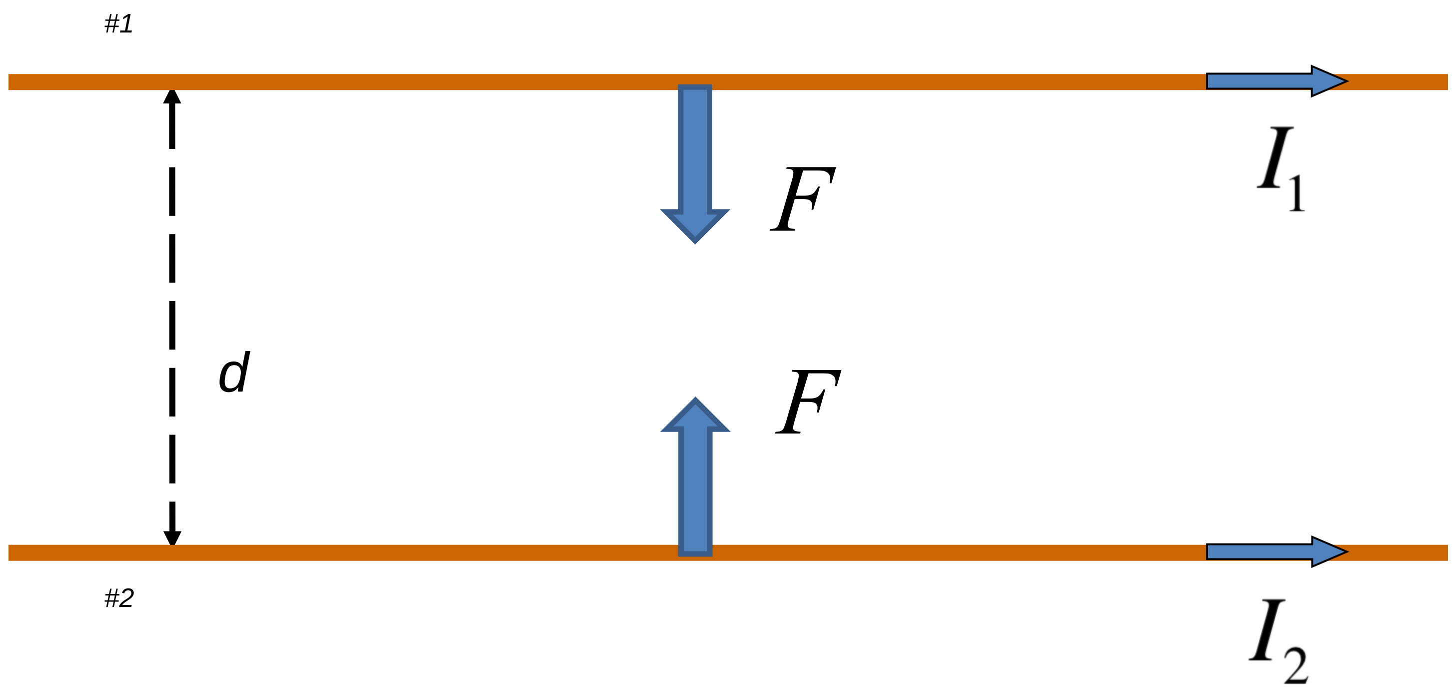
B



Which figure correctly represents **force** on the **upper** wire?



Force Between Two Parallel Wires



Derive an expression for the magnetic force on wire #2 due to the magnetic field created by the current flowing in wire #1.