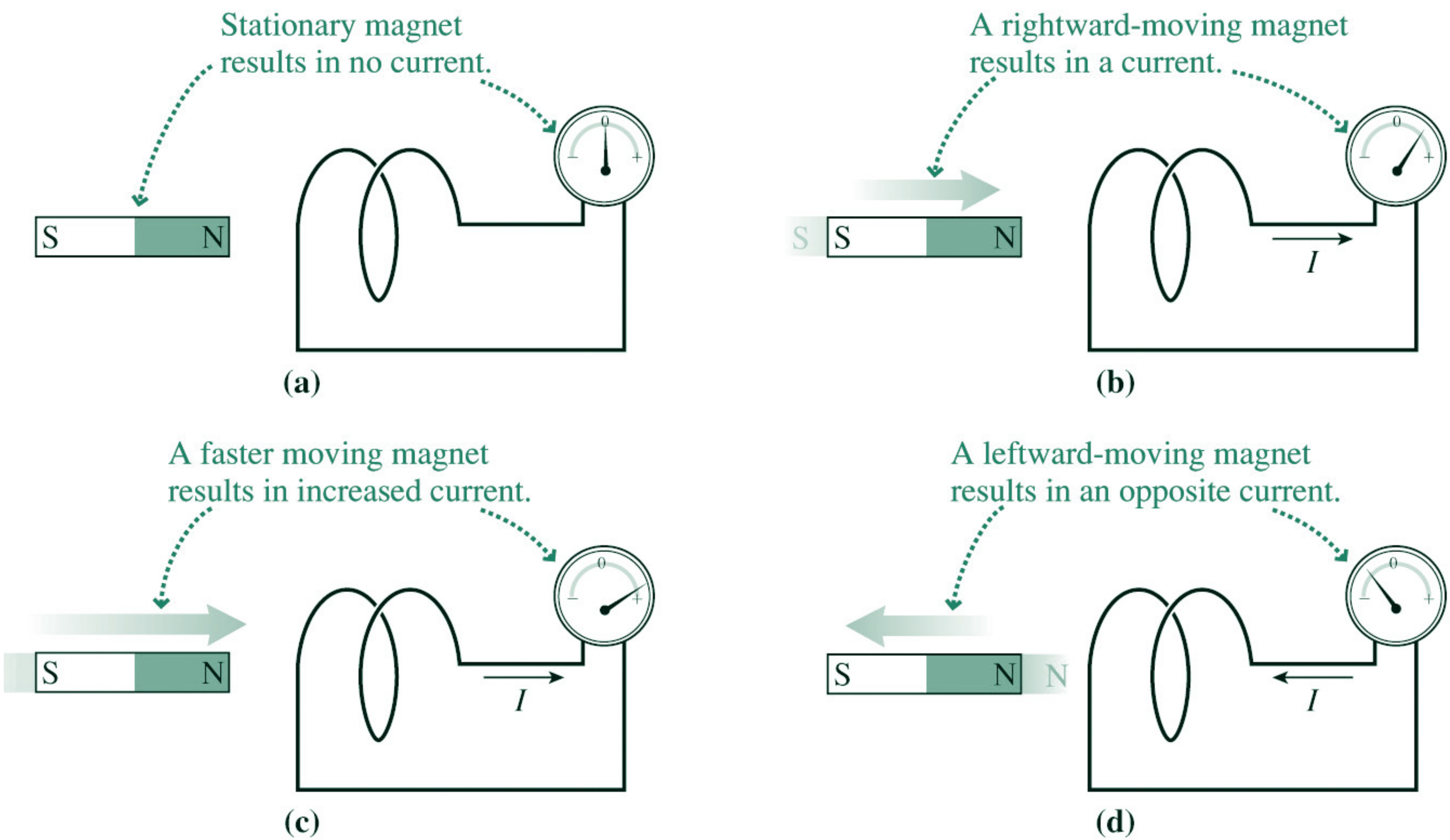
Chapter 27: Electromagnetic Induction
Tuesday October 25th

- **Normal lab schedule this week**
- **Discuss mid-term exam in recitations tomorrow**
- **Mini-exam 4 next Thursday**

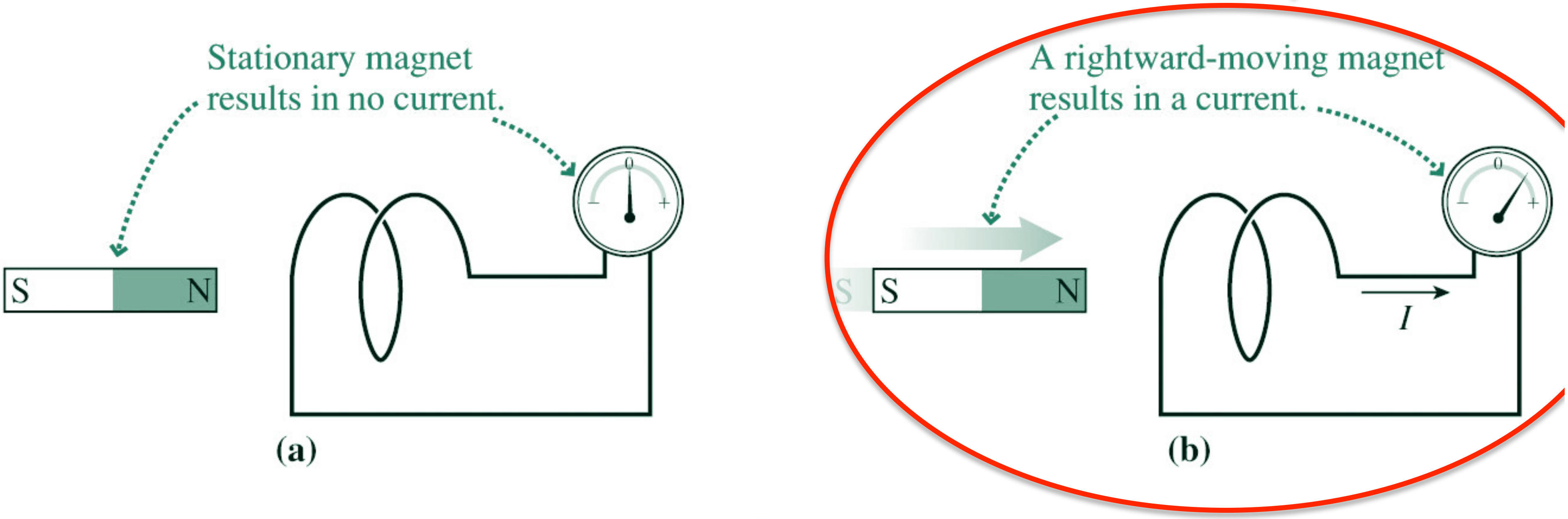
- Brief discussion of mid-term exam results
- Induced currents
  - Magnetic flux and induced currents
  - Induced Electromotive Force and Faraday's Law
- Motional Electromotive Force
  - Connection between Faraday and Lorentz Force Laws
  - Relativistic Invariance
- Lenz's law
- Inductance (if time)

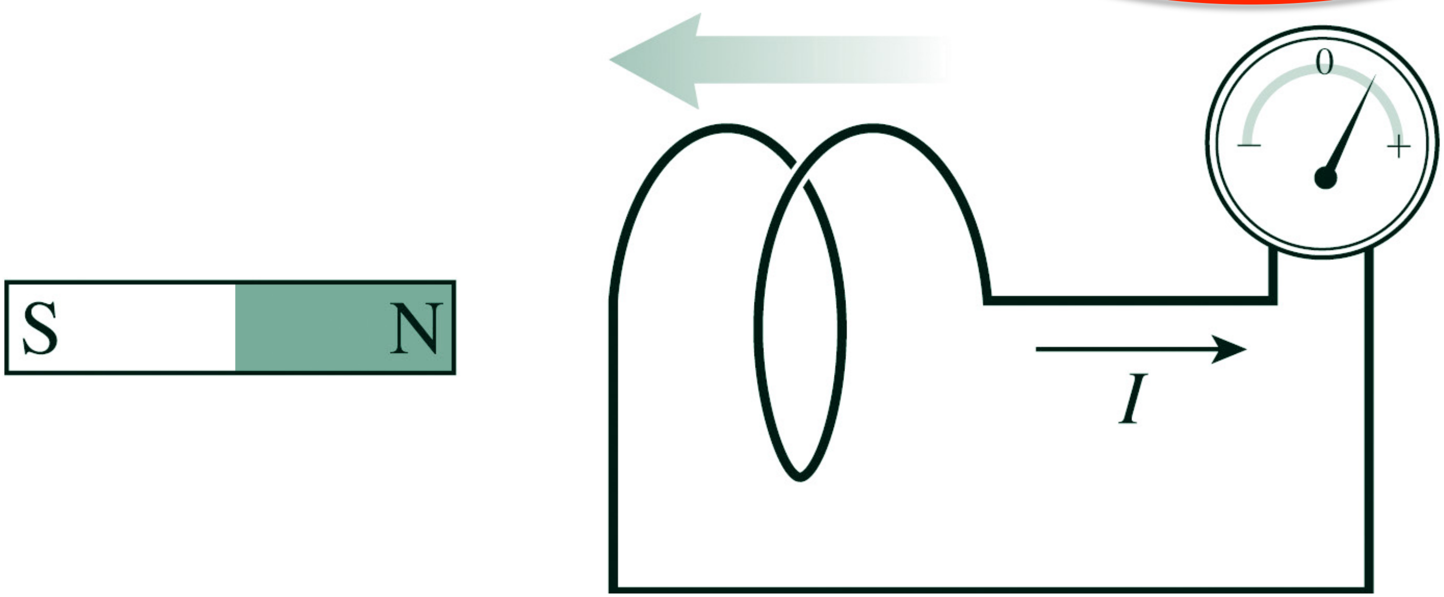
Reading: up to page 477 in the text book (Ch. 27)

Induced Currents



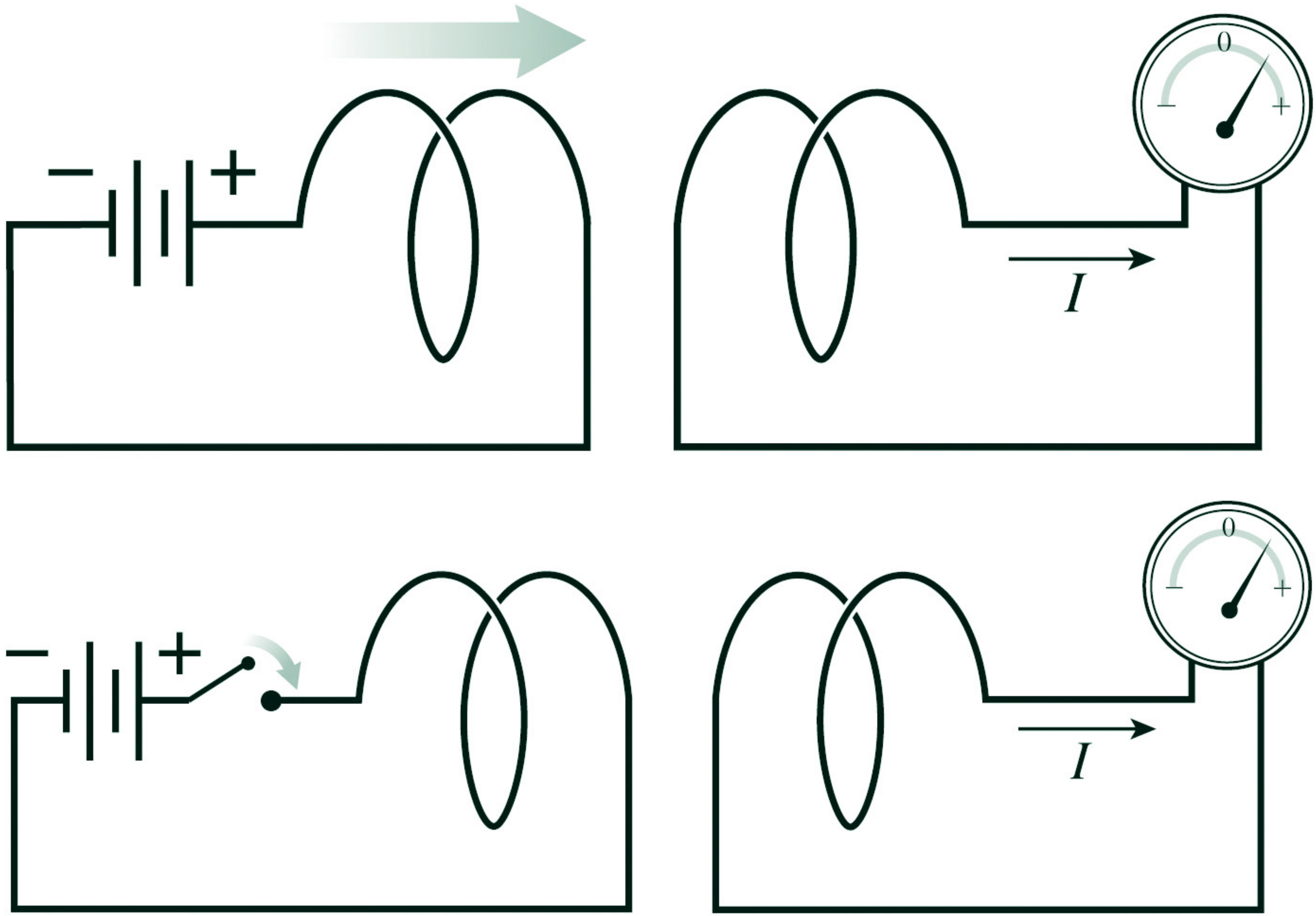
Induced Currents and Relativity



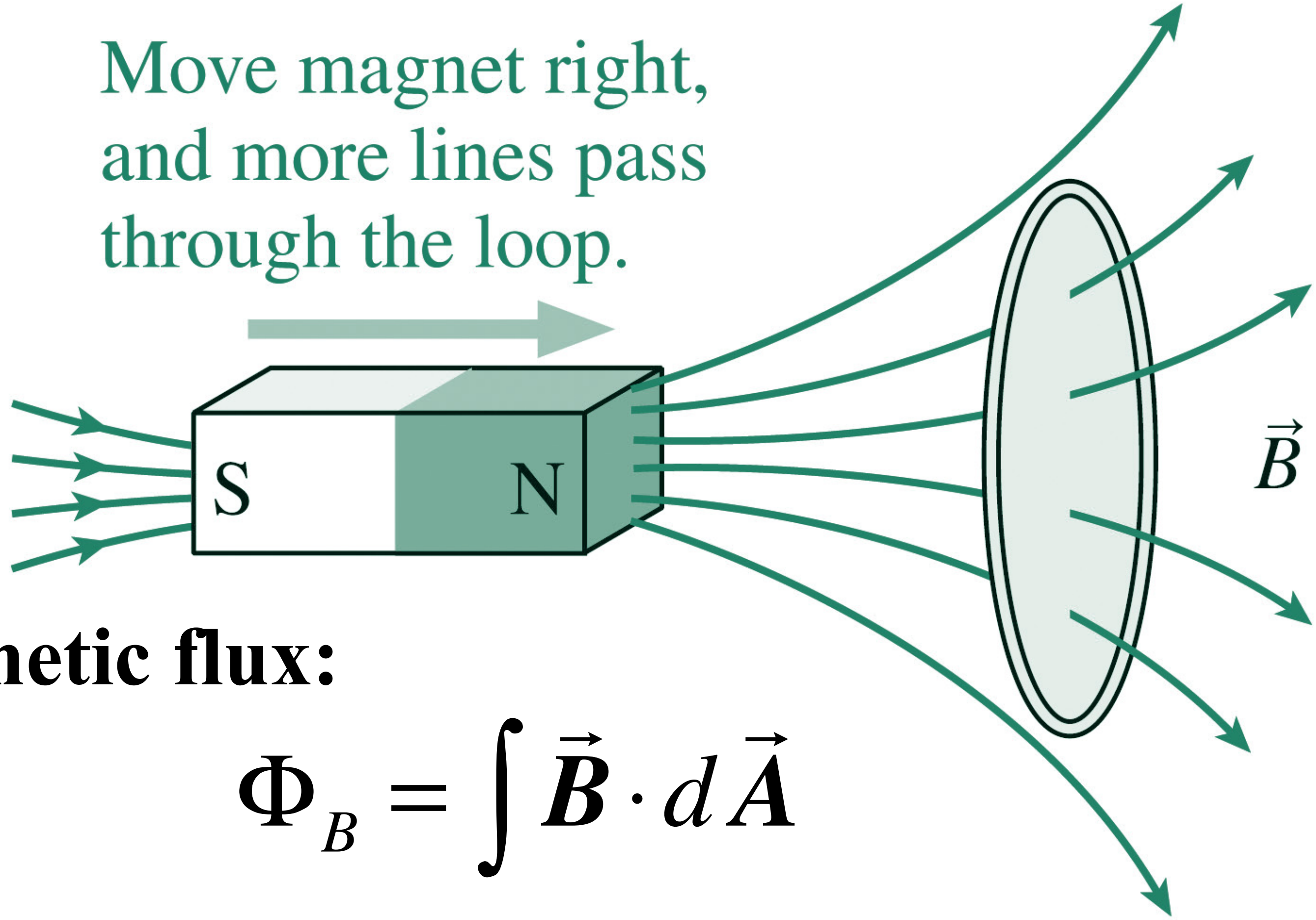


What happens if you move the coil instead of the magnet?

Induced Currents and Time Varying Fields



Flux and Induced Electromotive Force



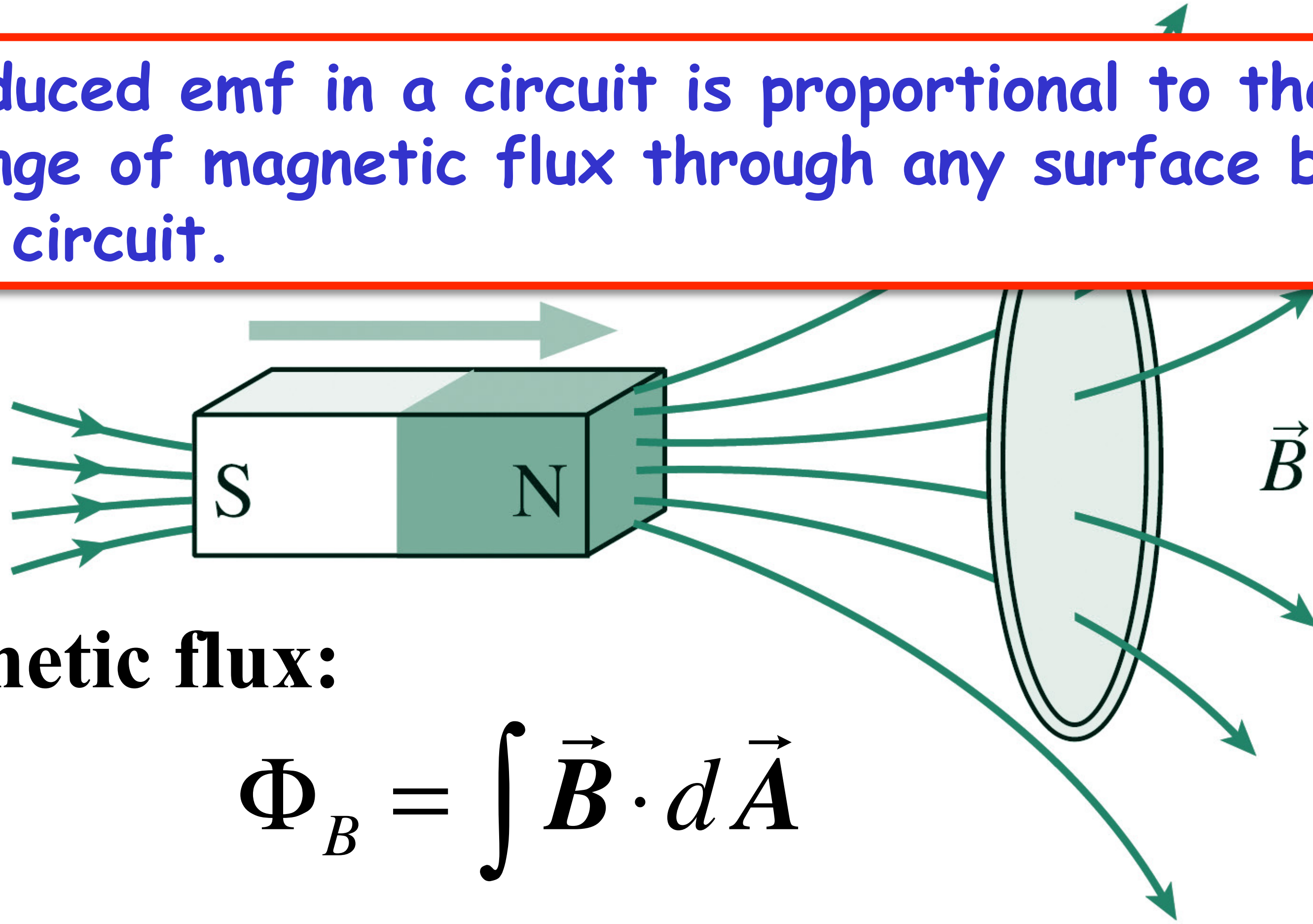
Magnetic flux:

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

- It's apparently the change in magnetic flux through a current loop that is responsible for the induced current in the loop.
- In a circuit, we talk about an emf as being the driving force for the current, i.e., the changing magnetic flux induces an emf in the circuit.

Putting it All Together: Faraday's Law

The induced emf in a circuit is proportional to the rate of change of magnetic flux through any surface bound by the circuit.



Magnetic flux:

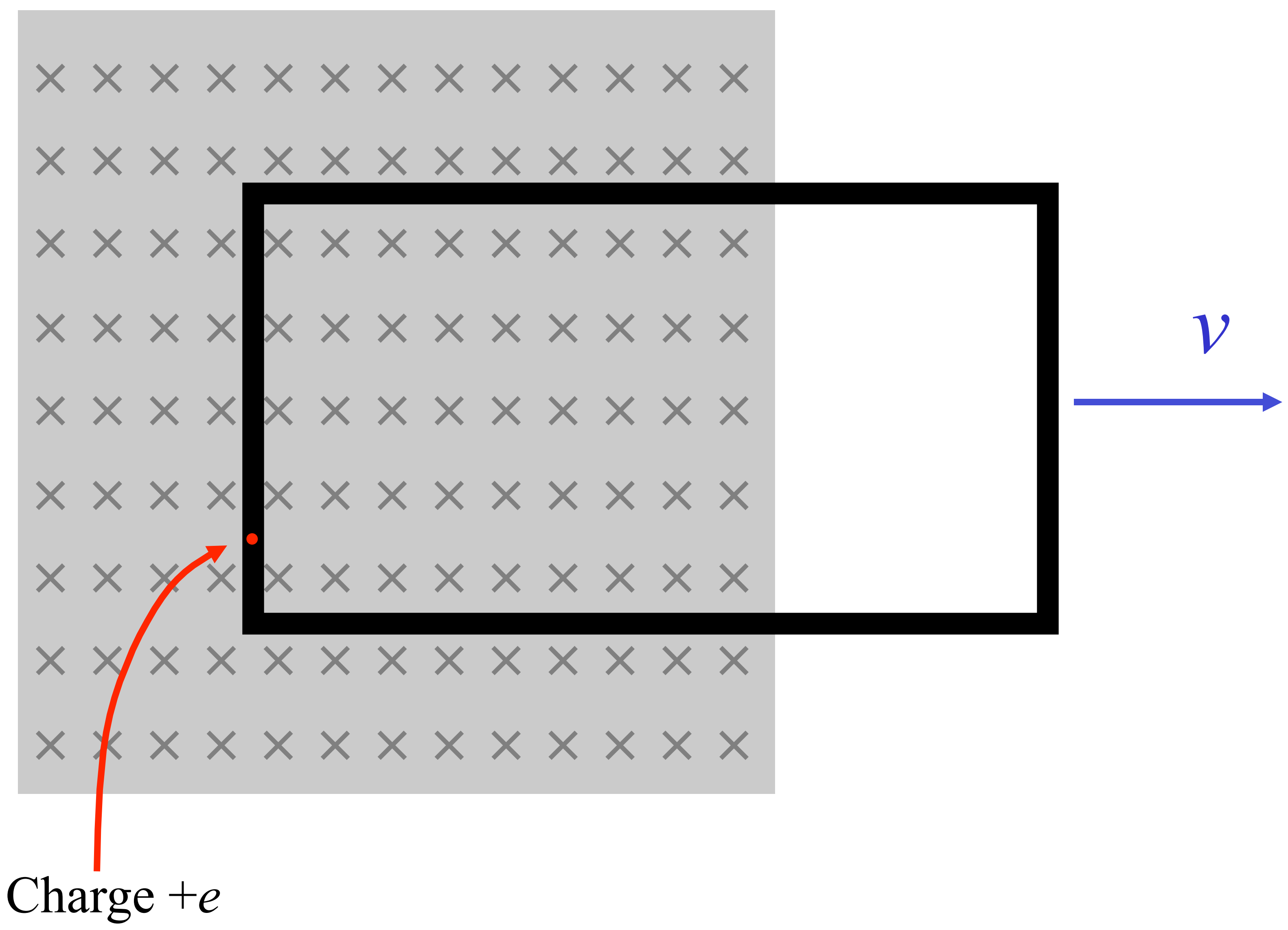
$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

$$\varepsilon = -\frac{d\Phi_B}{dt} = IR$$

The minus sign turns out to be very important

Motional emf

B-field into page



Motional emf

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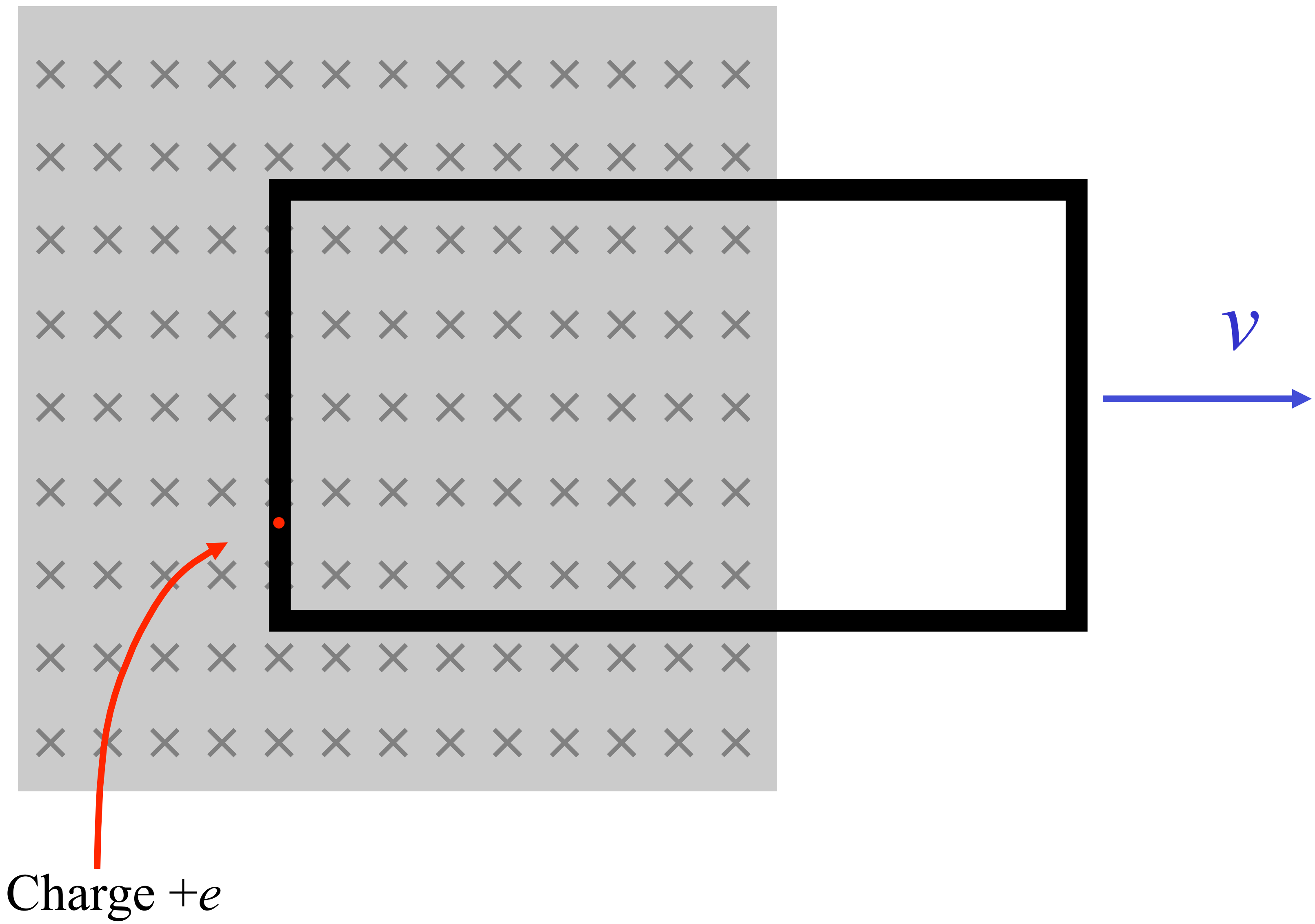

Motional emf

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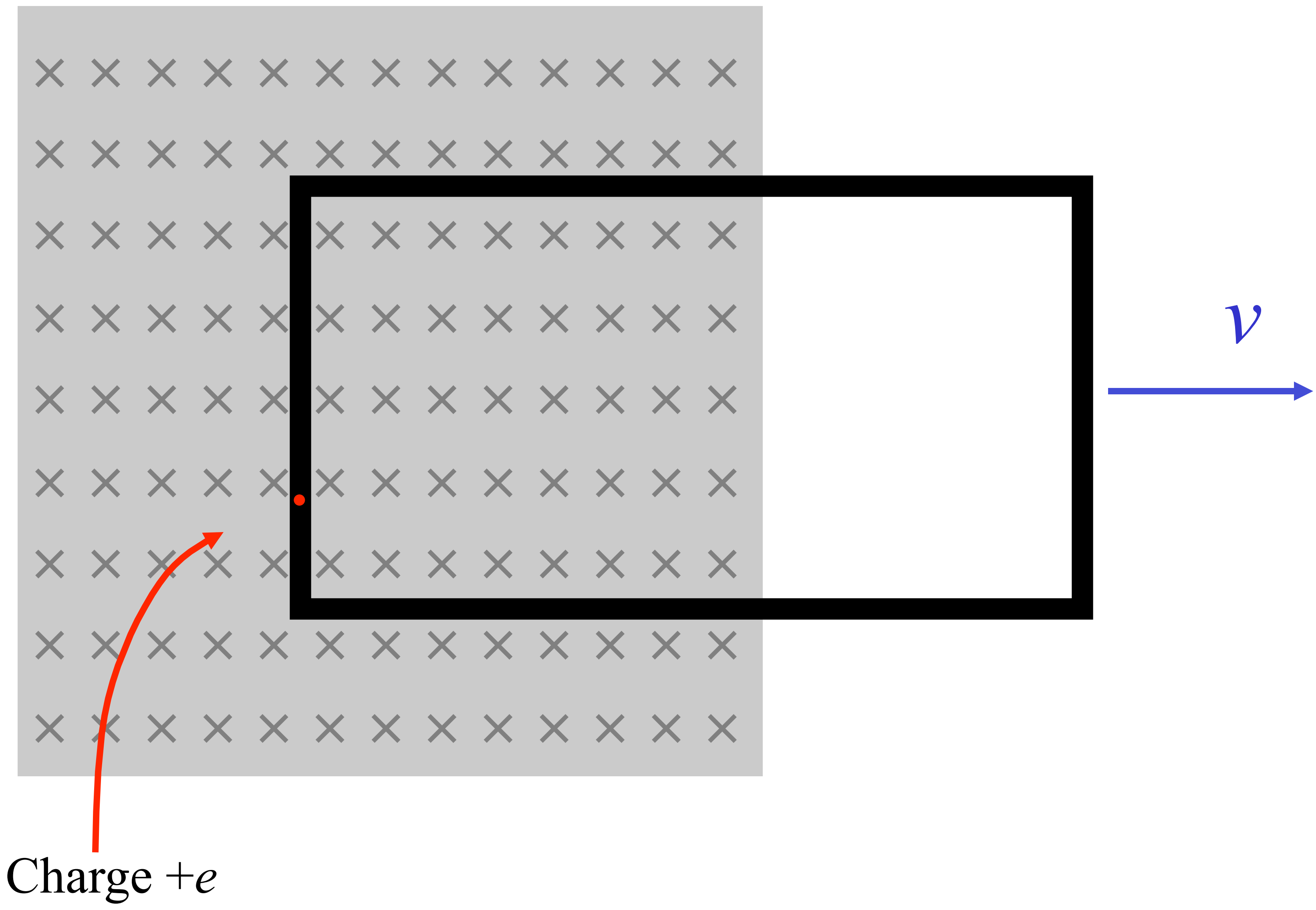
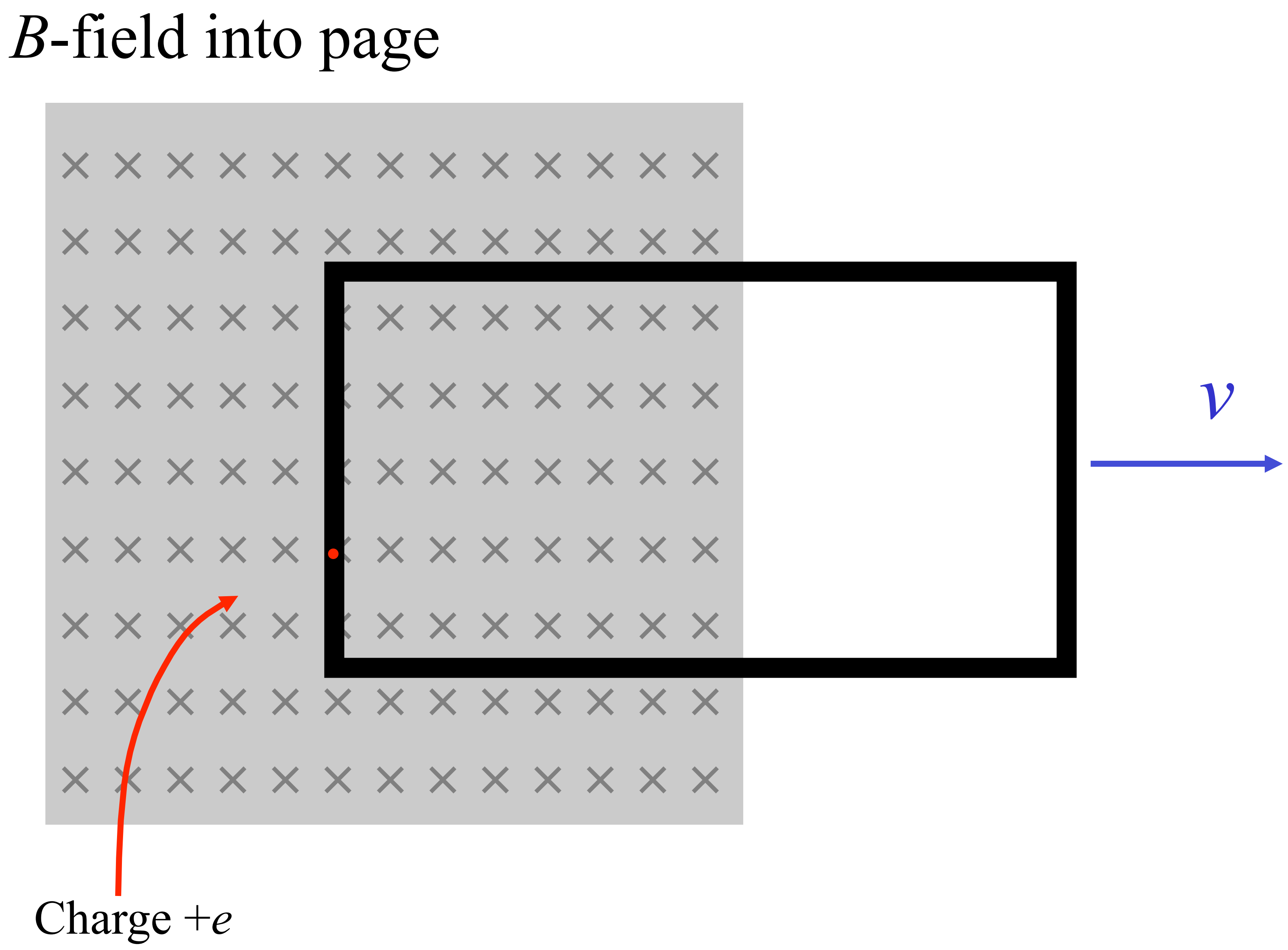


Motional emf



Motional emf

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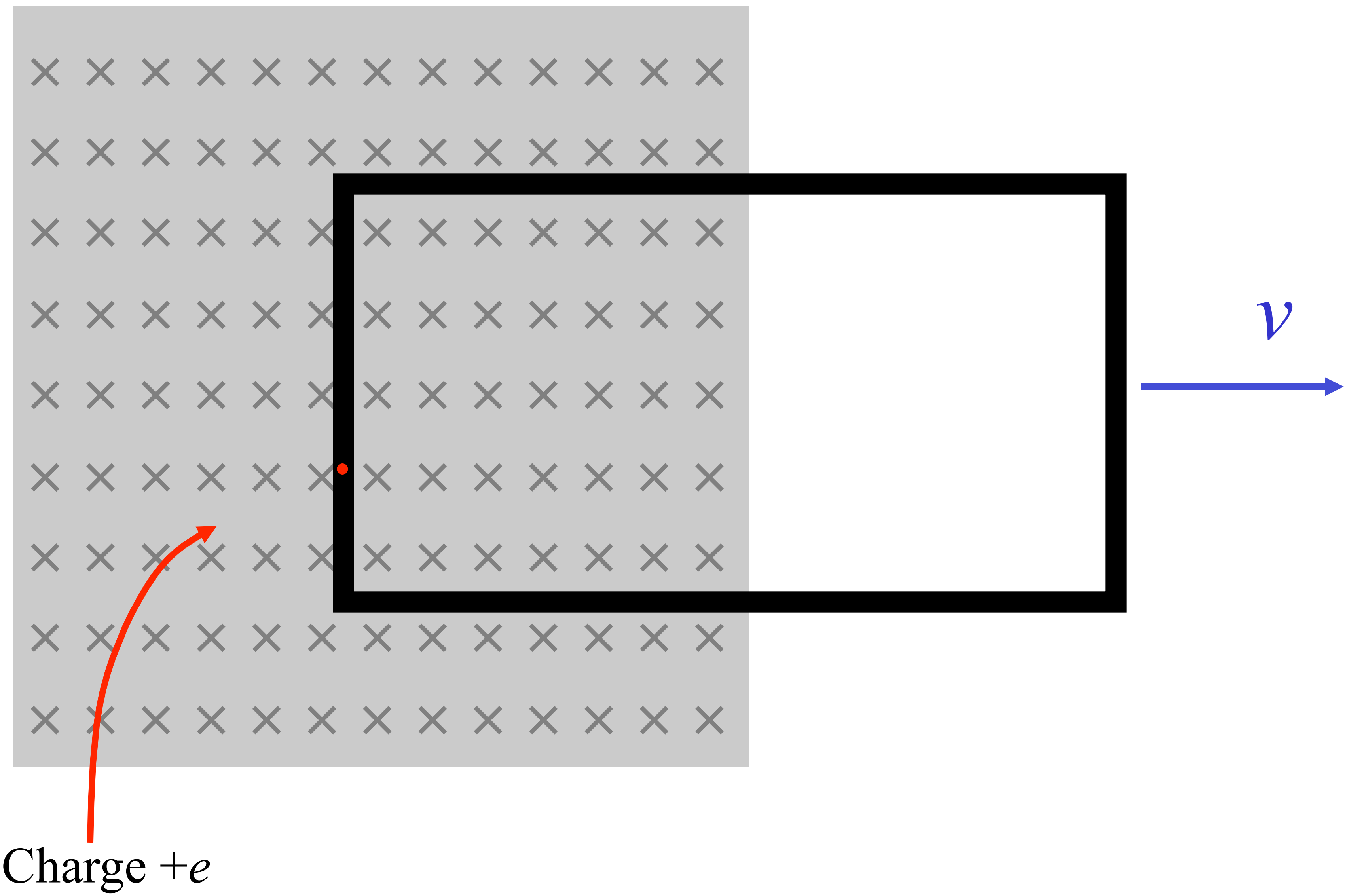
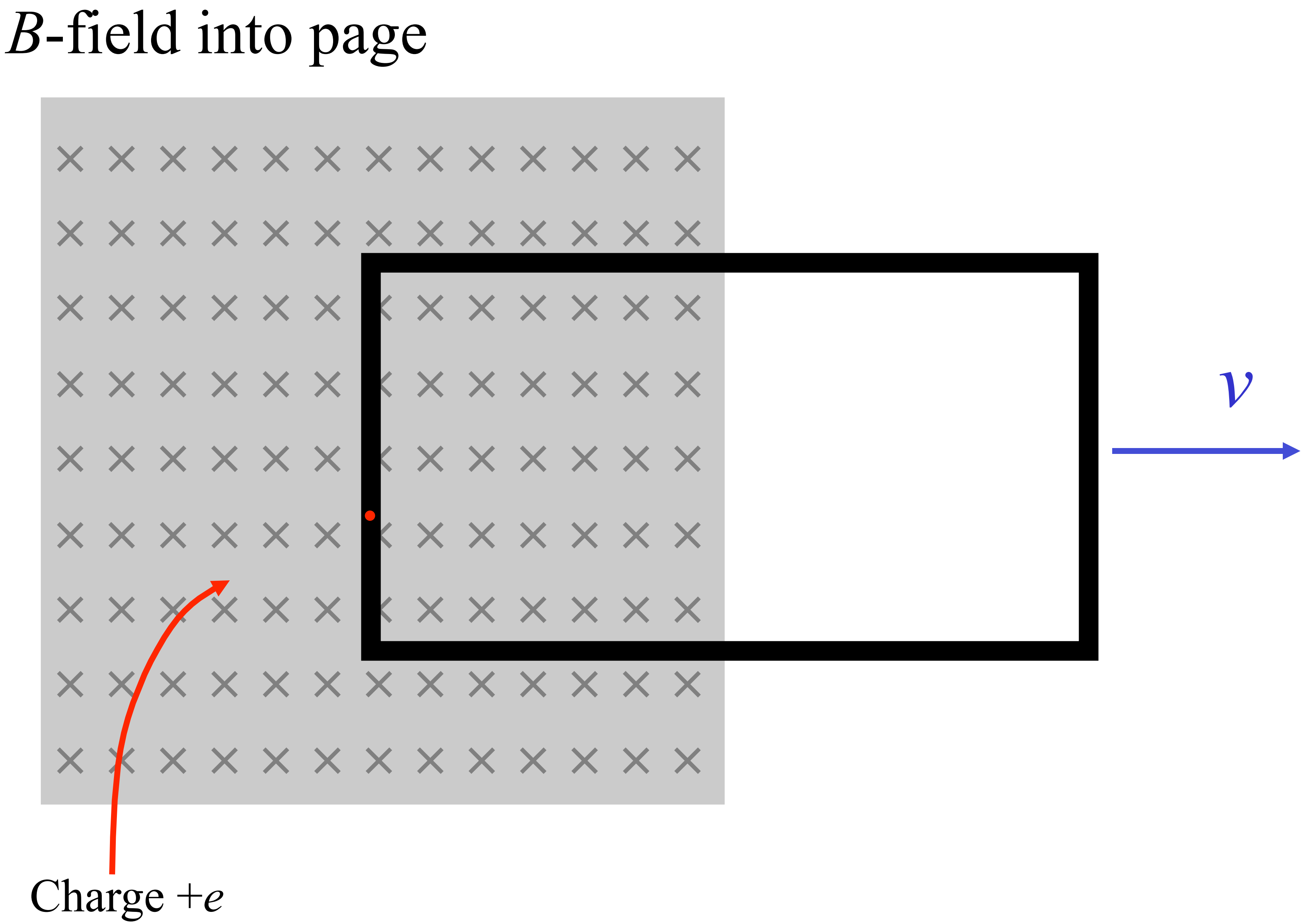
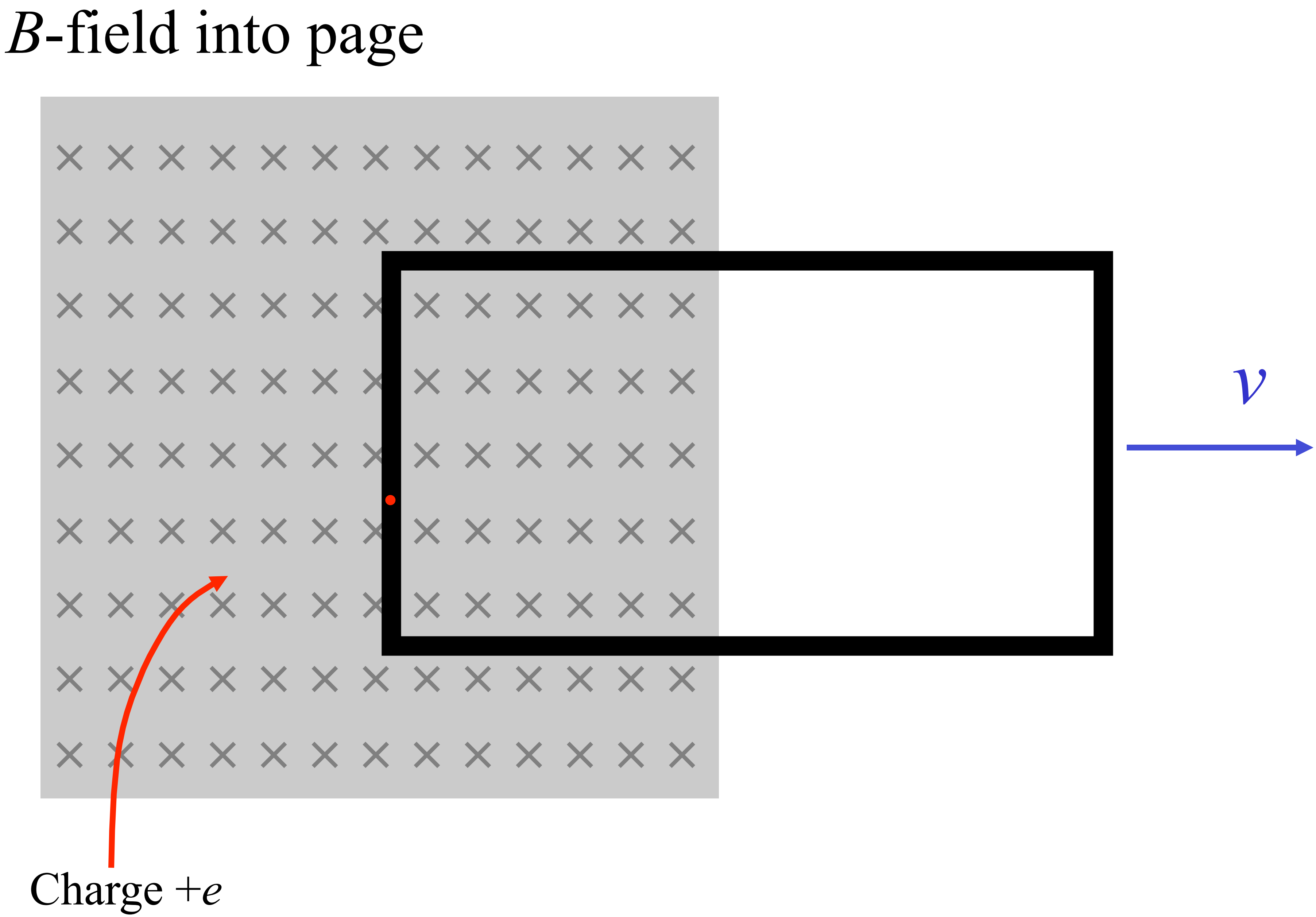


Motional emf



Motional emf



Motional emf

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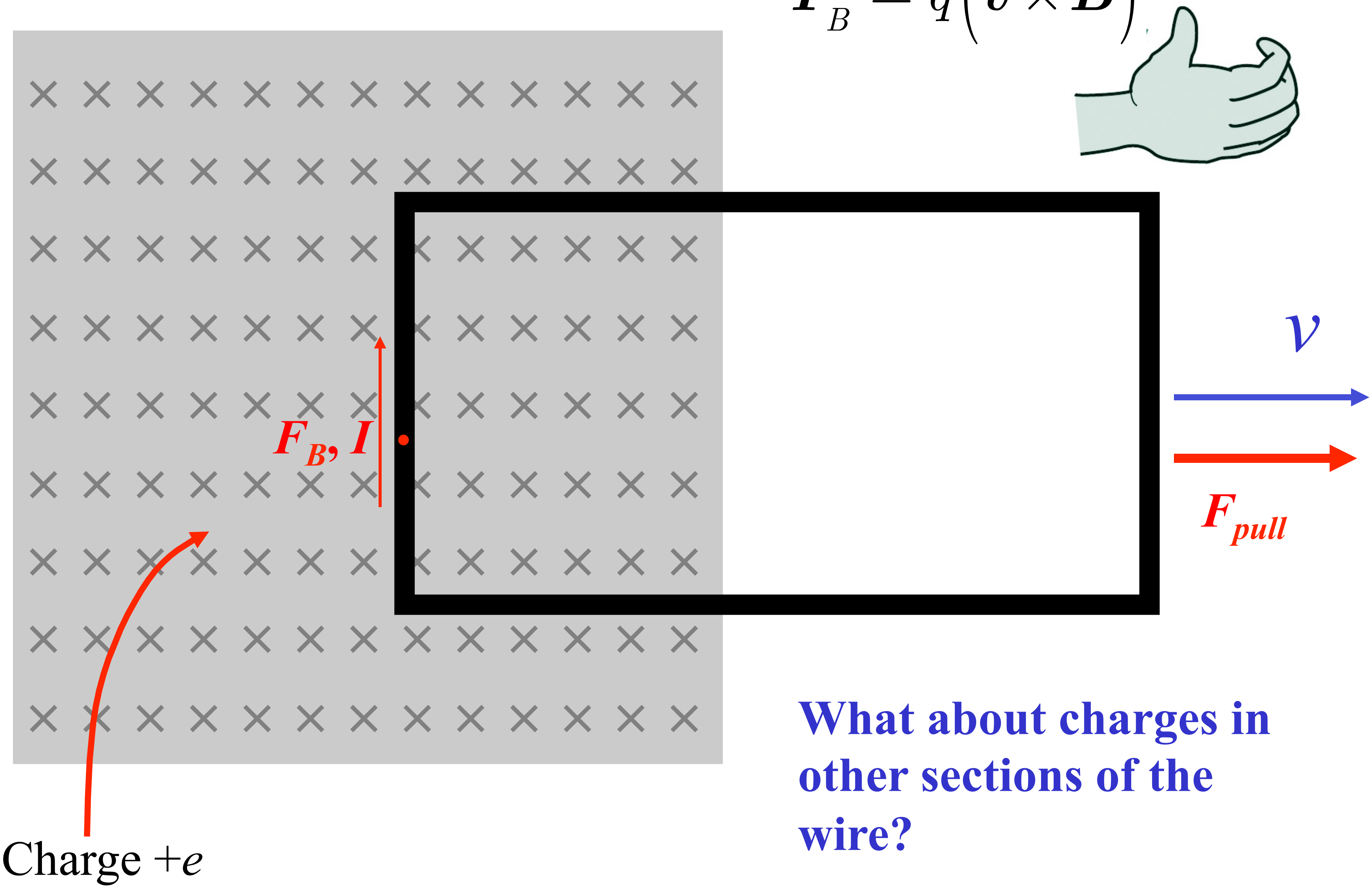
$$\vec{F}_B = q\left(\vec{v} \times \vec{B}\right)$$



What about charges in other sections of the wire?

Motional emf

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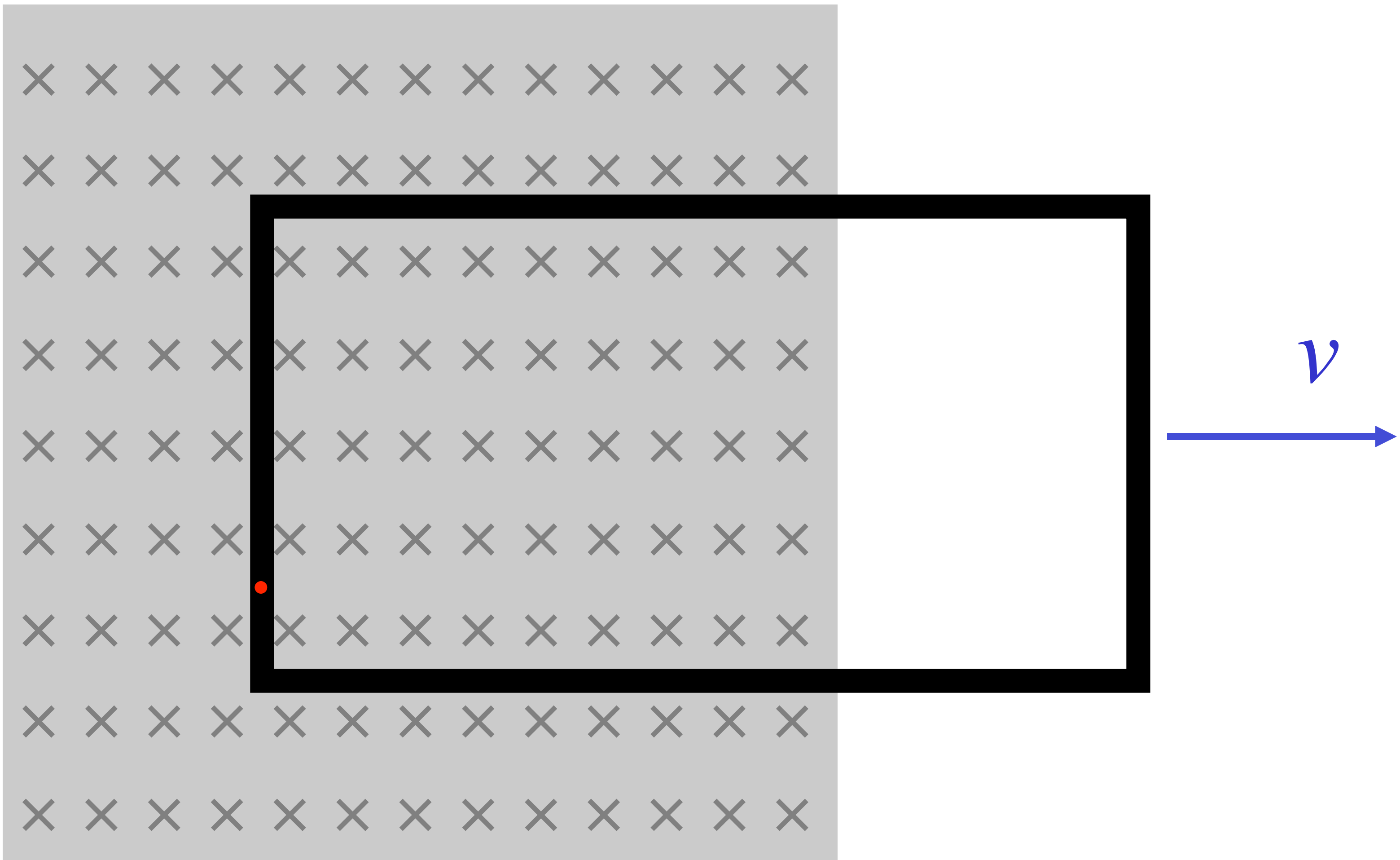

Motional emf

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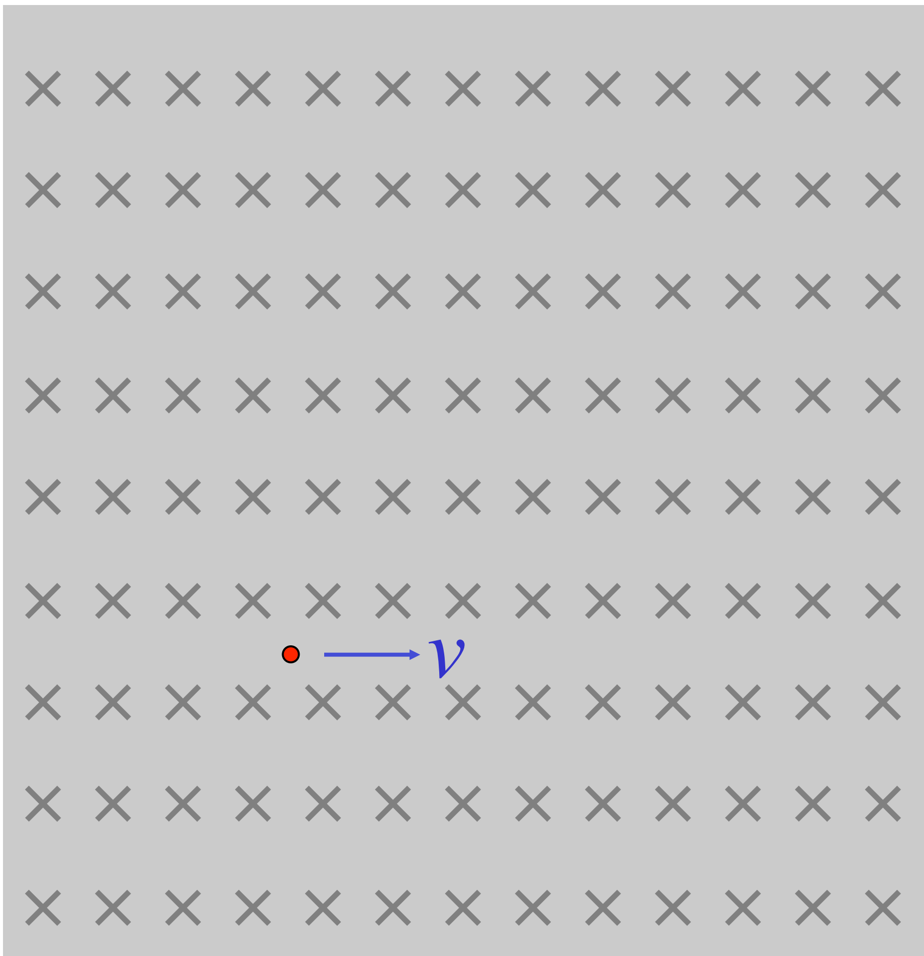

Motional emf

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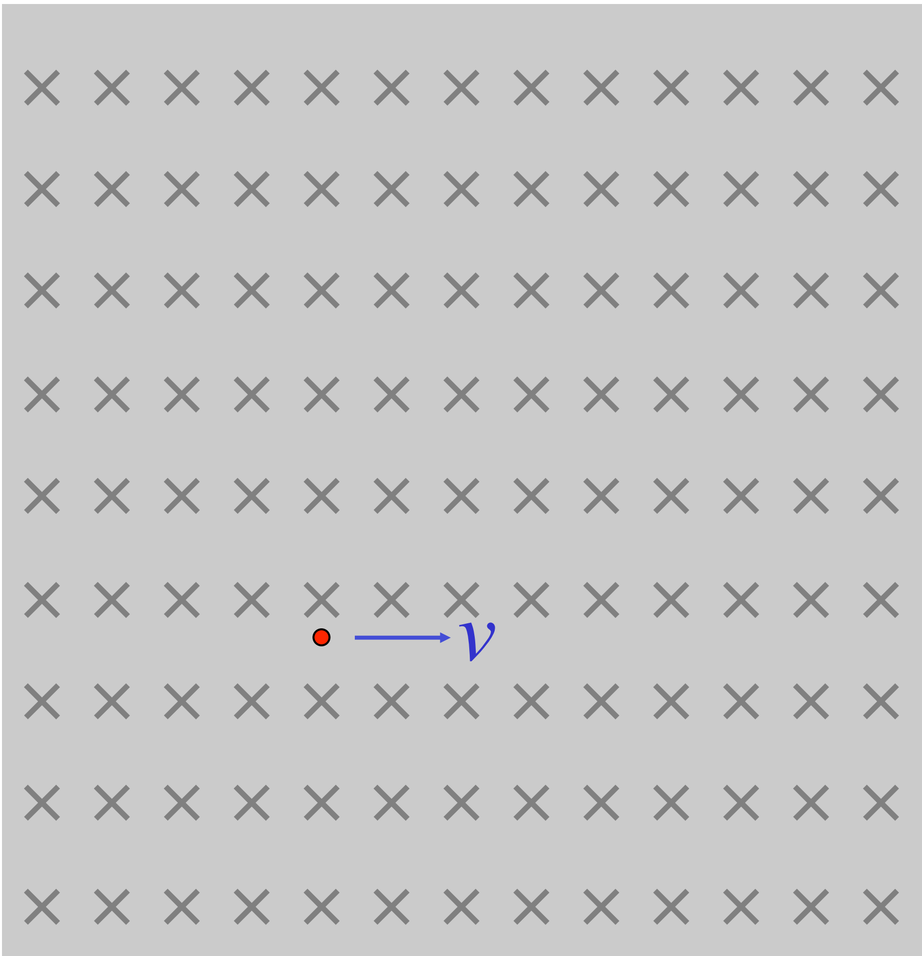

Motional emf

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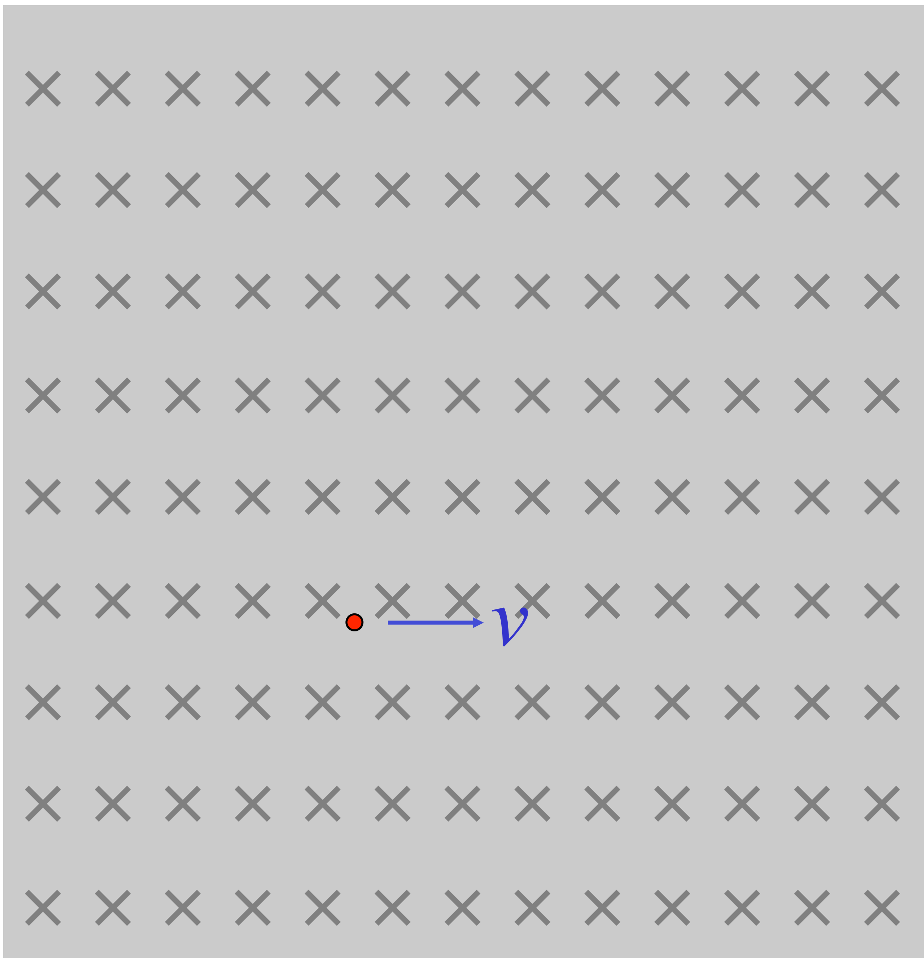

Motional emf

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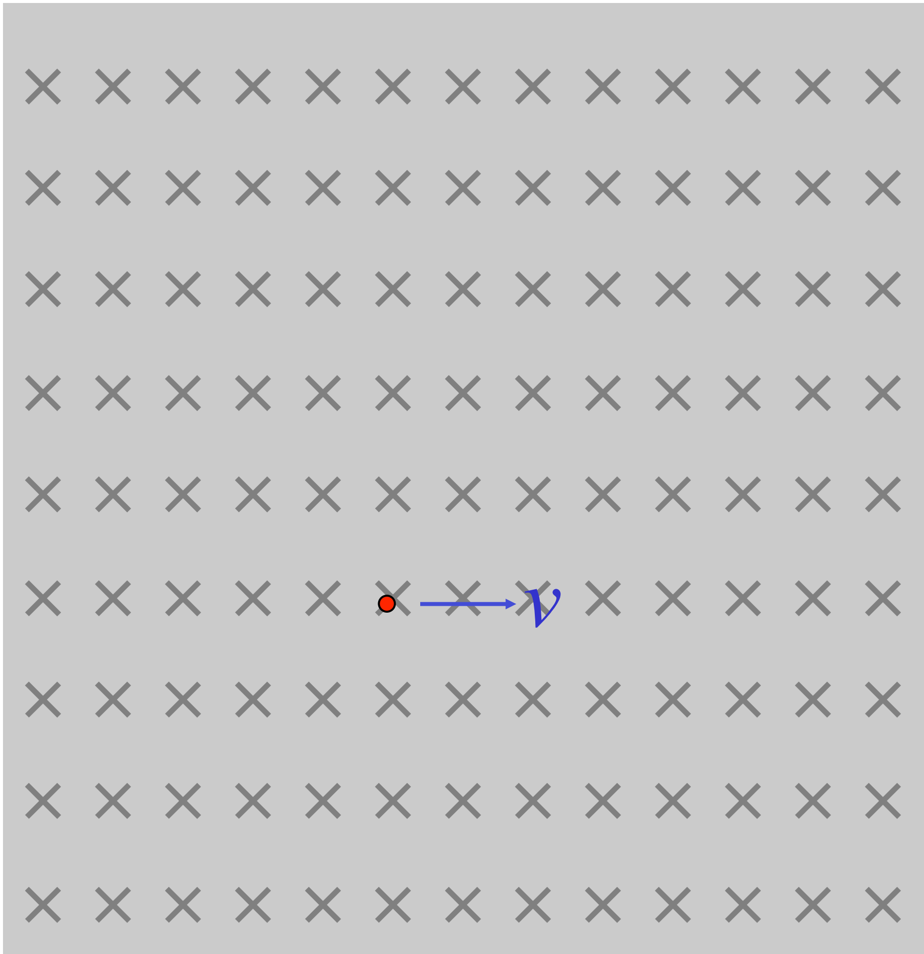

Motional emf

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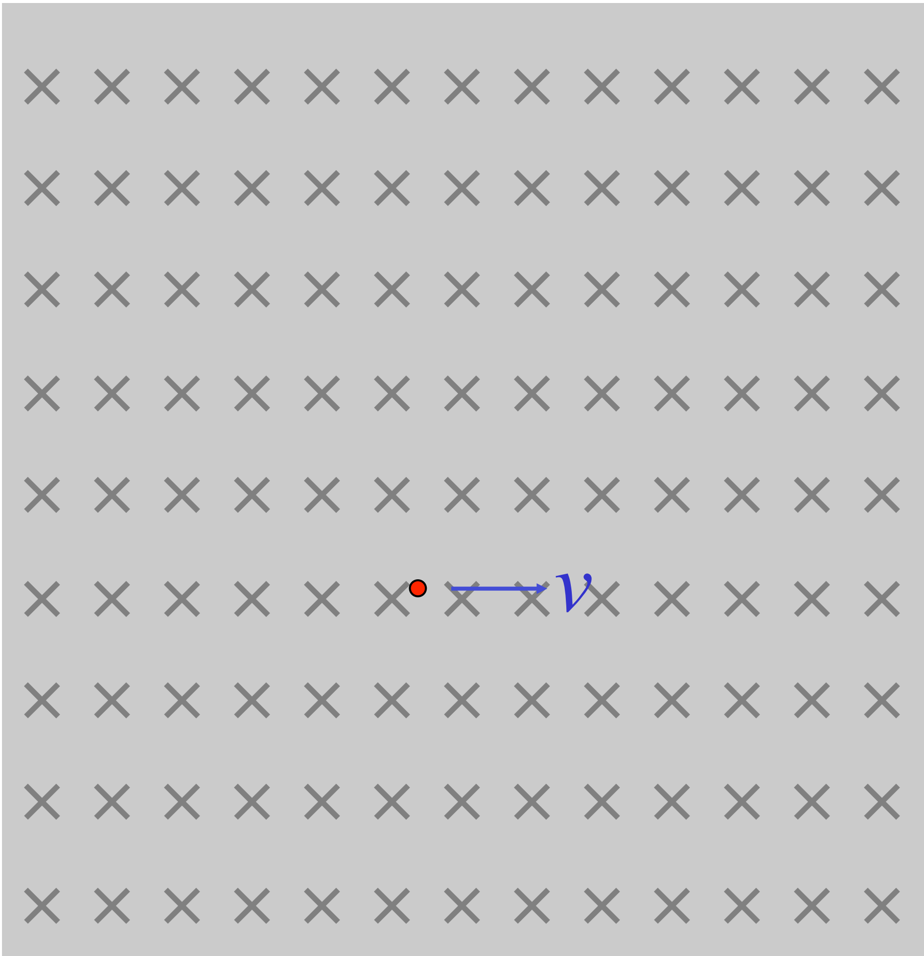

Motional emf

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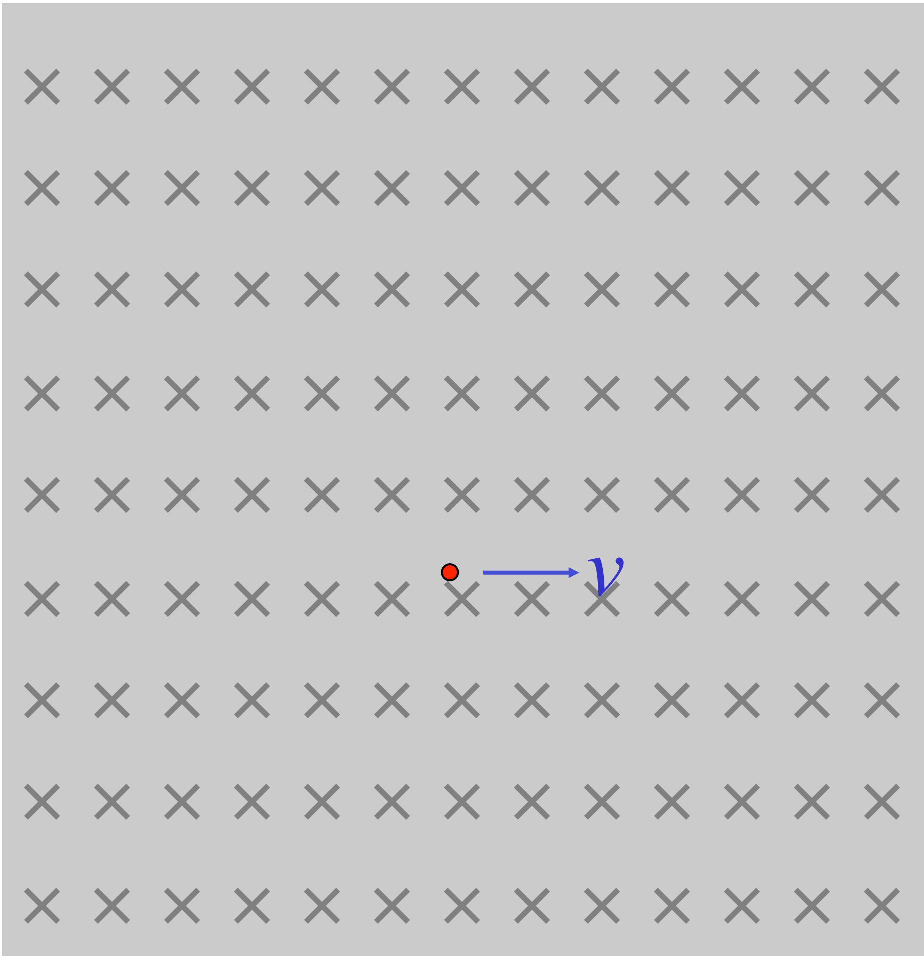

Motional emf

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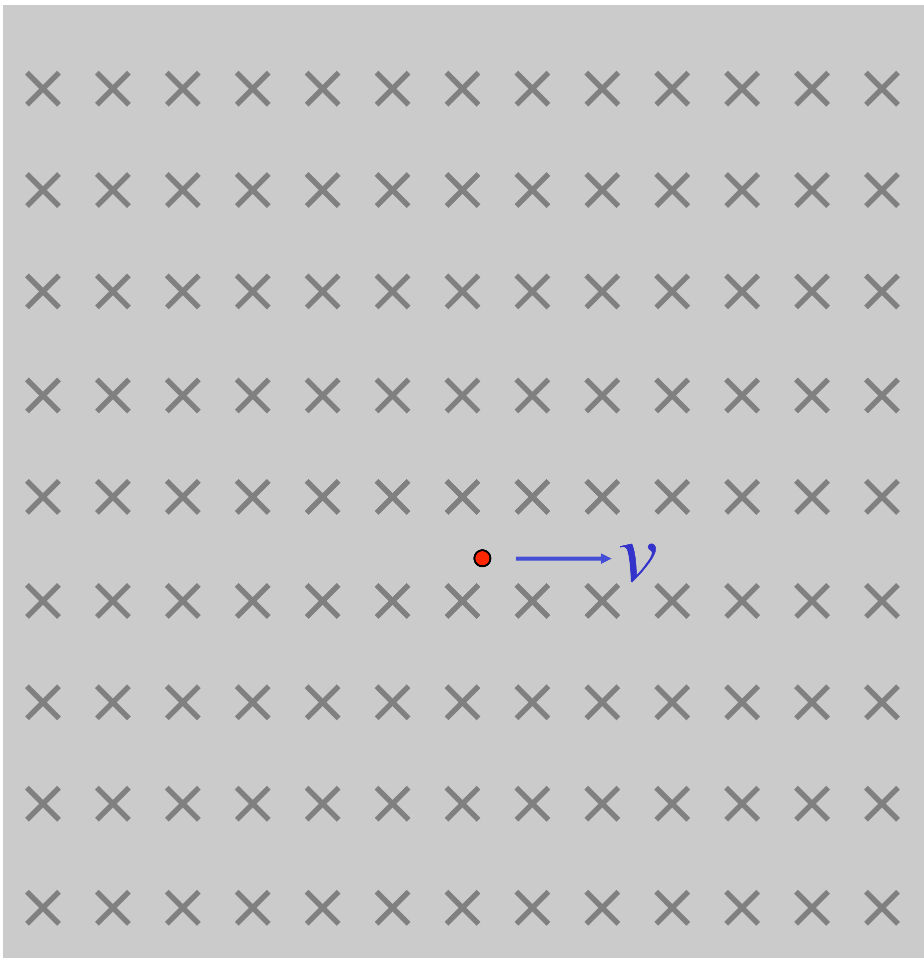

Motional emf

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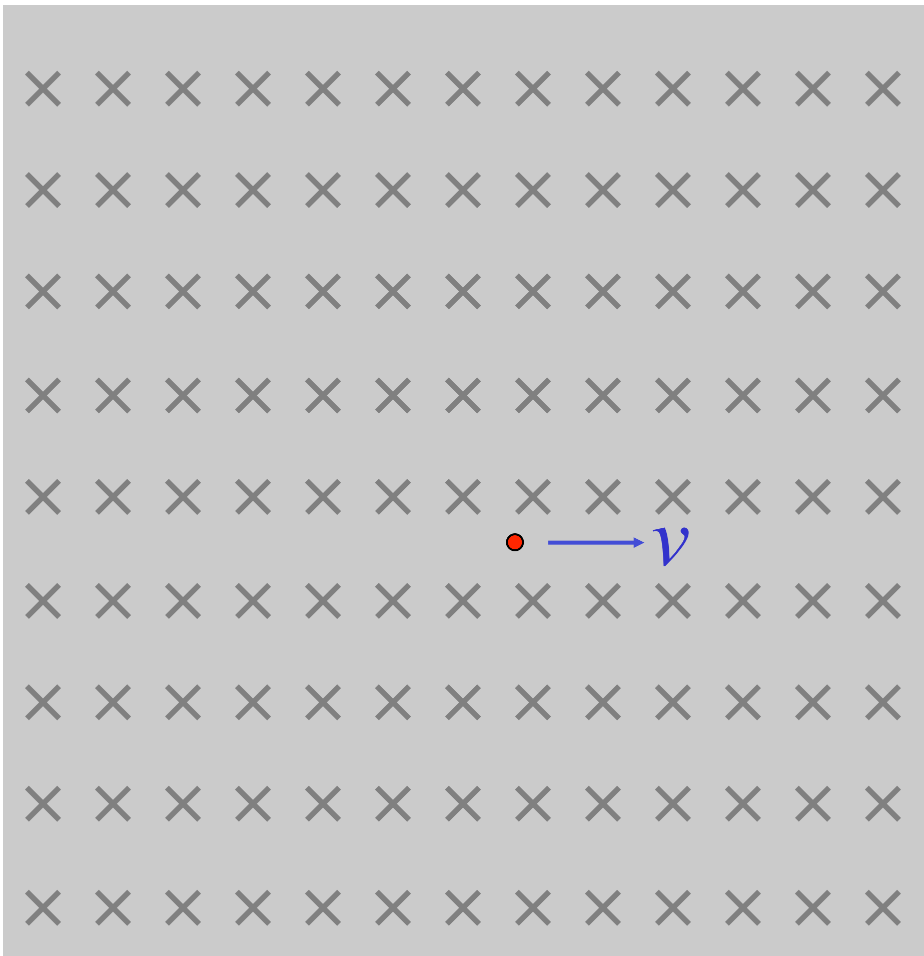

Motional emf

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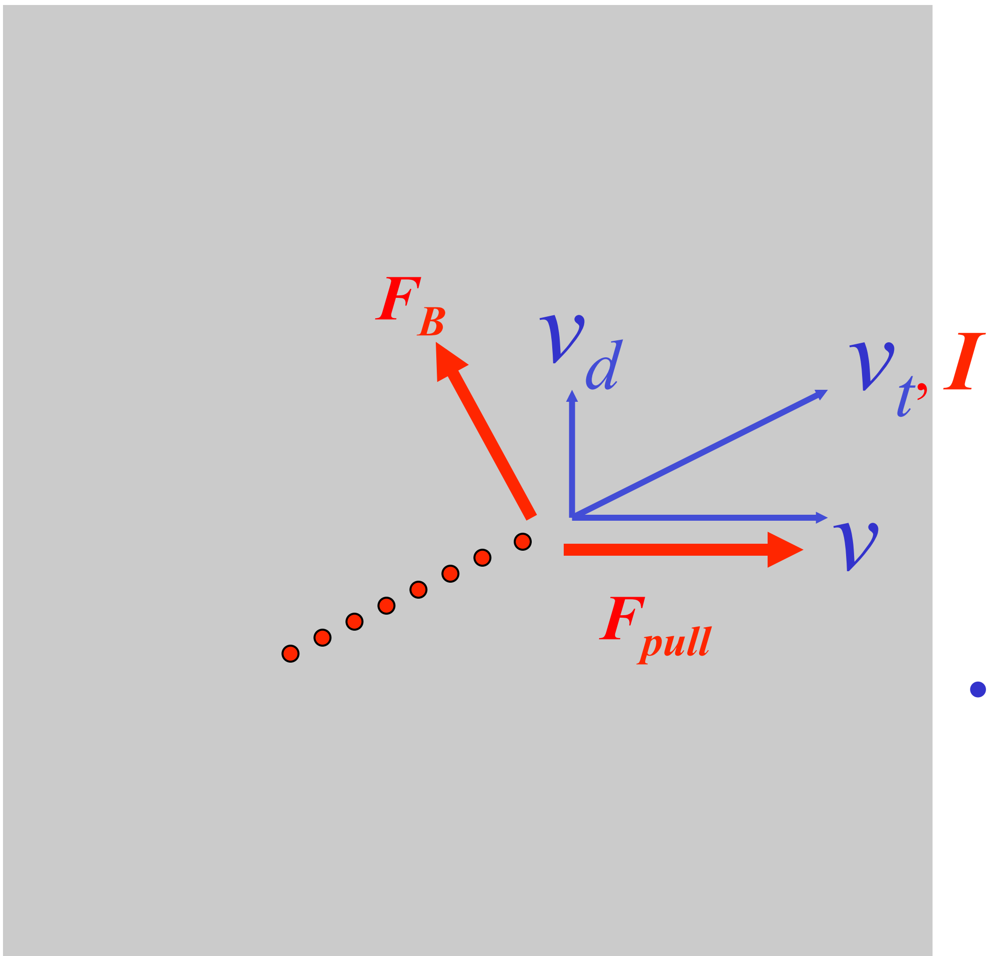
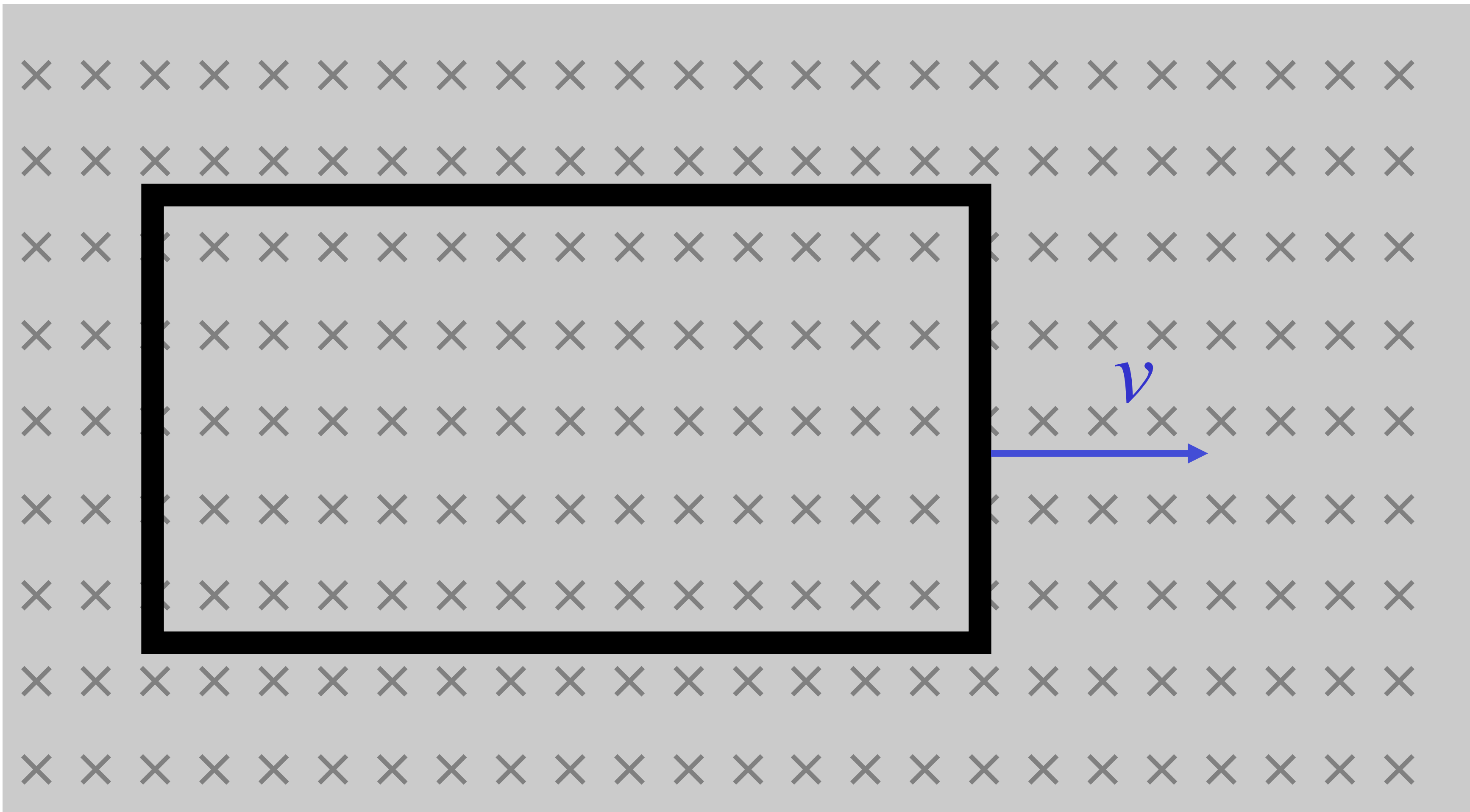


- **The magnetic field apparently performs no work, yet the person pulling is doing work.**
- **Where does that energy go?**

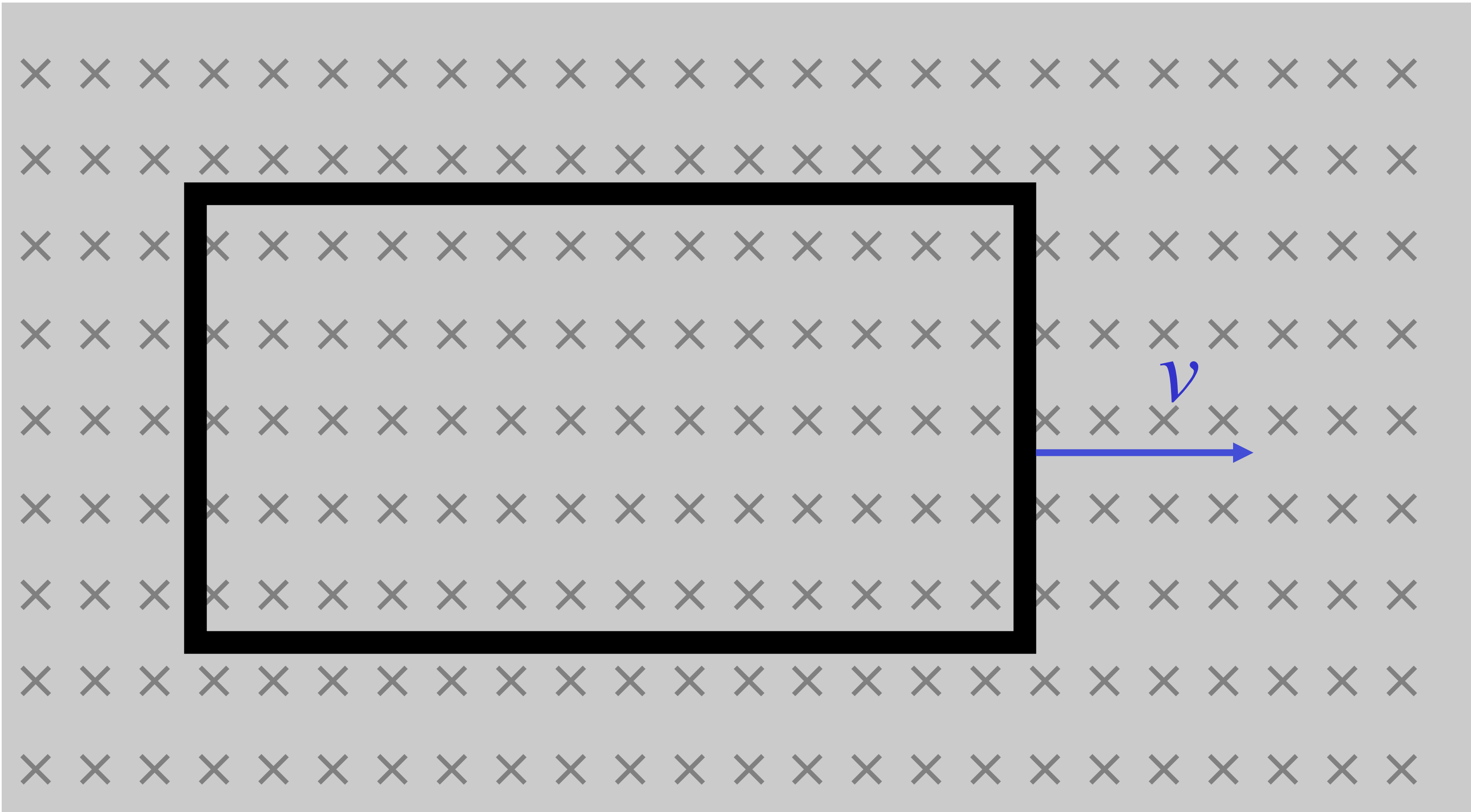
Motional emf

What about this situation?



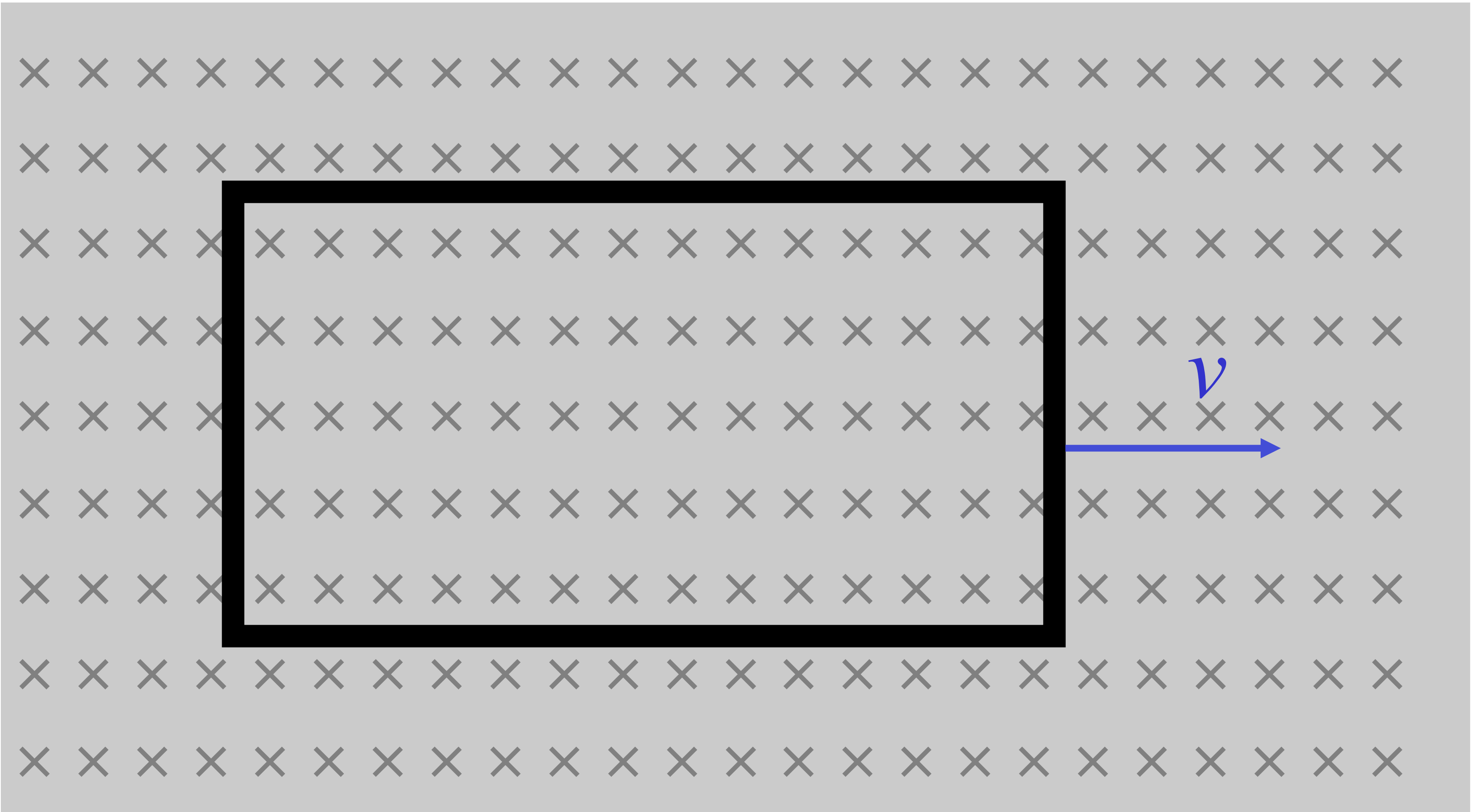
Motional emf

What about this situation?



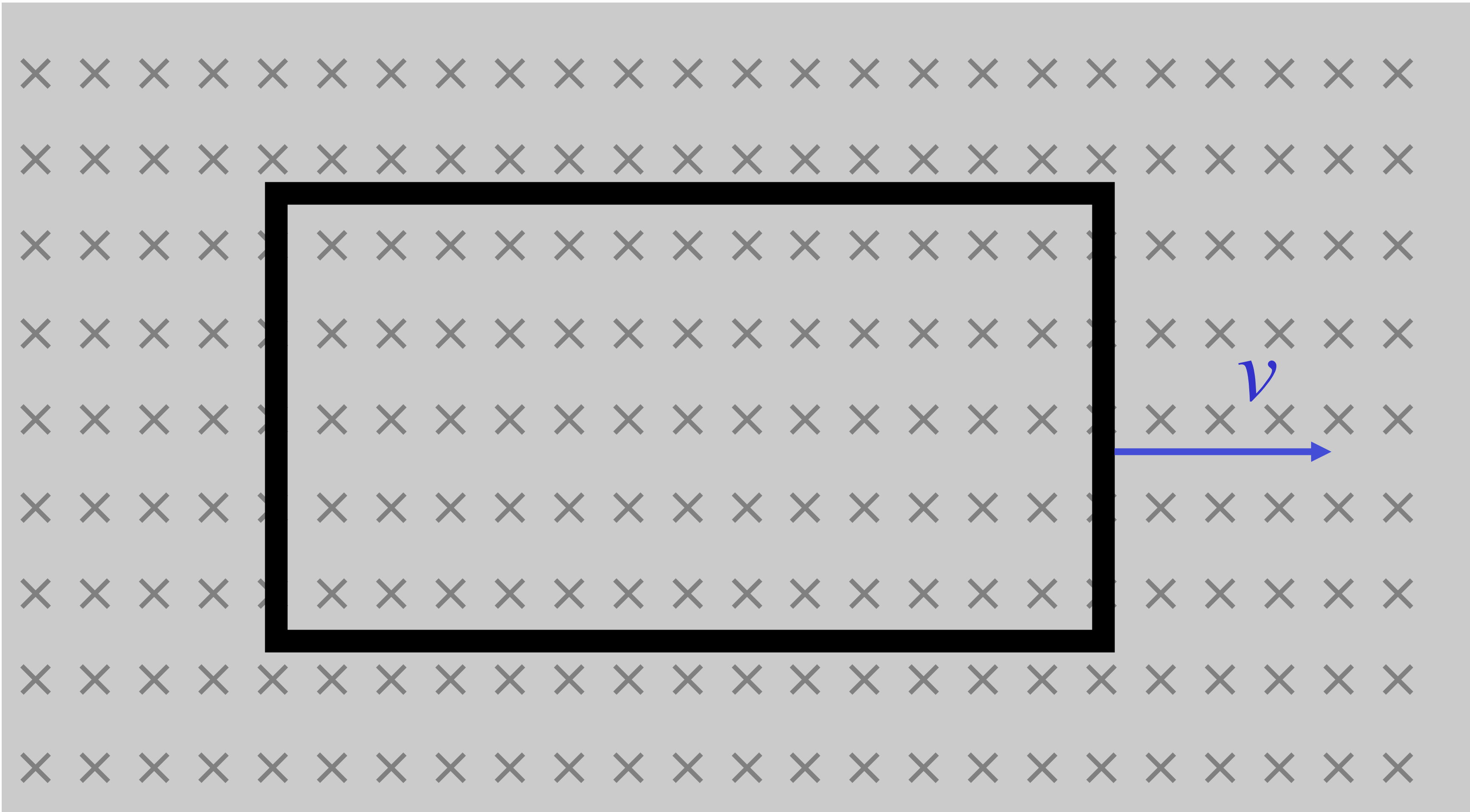
Motional emf

What about this situation?



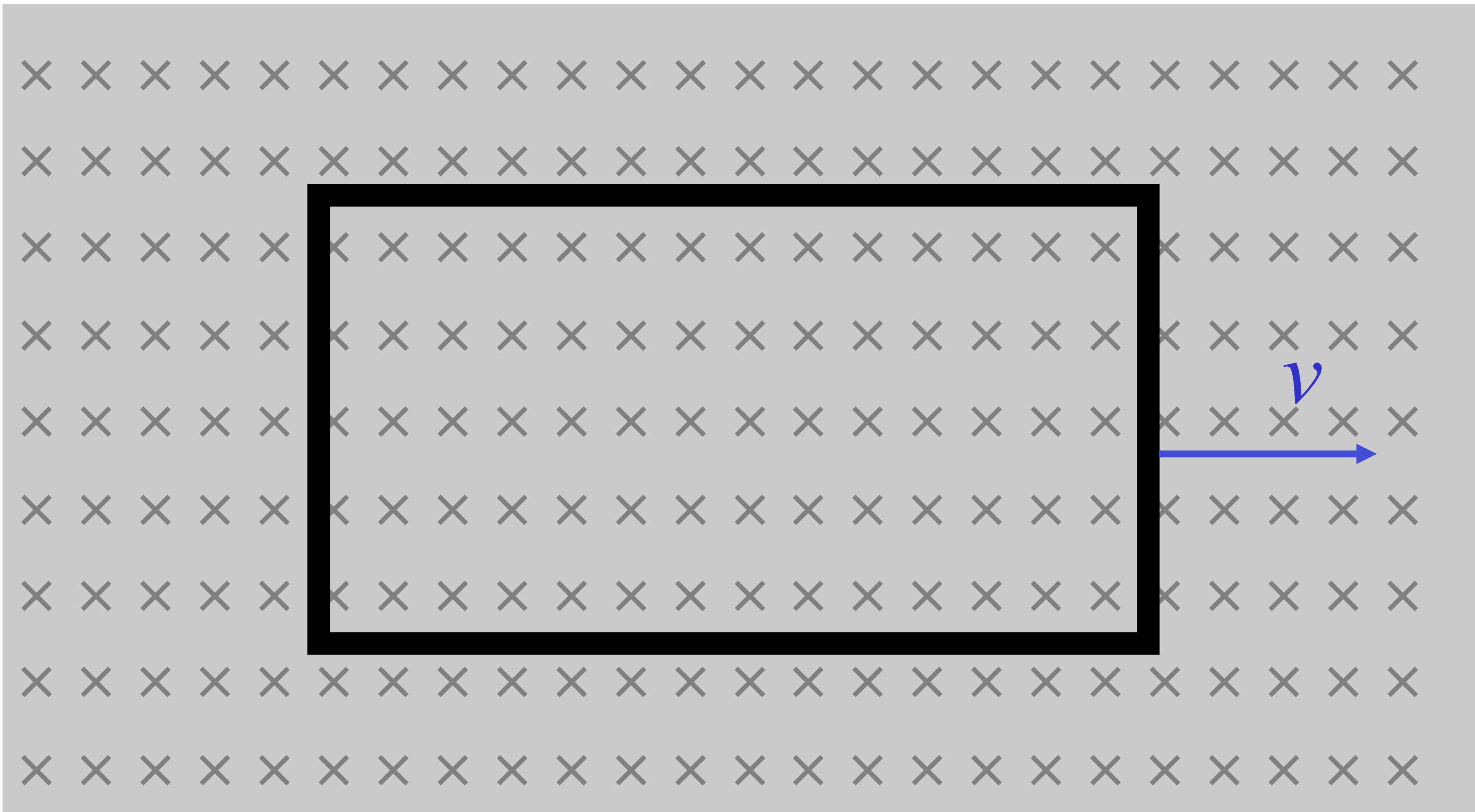
Motional emf

What about this situation?



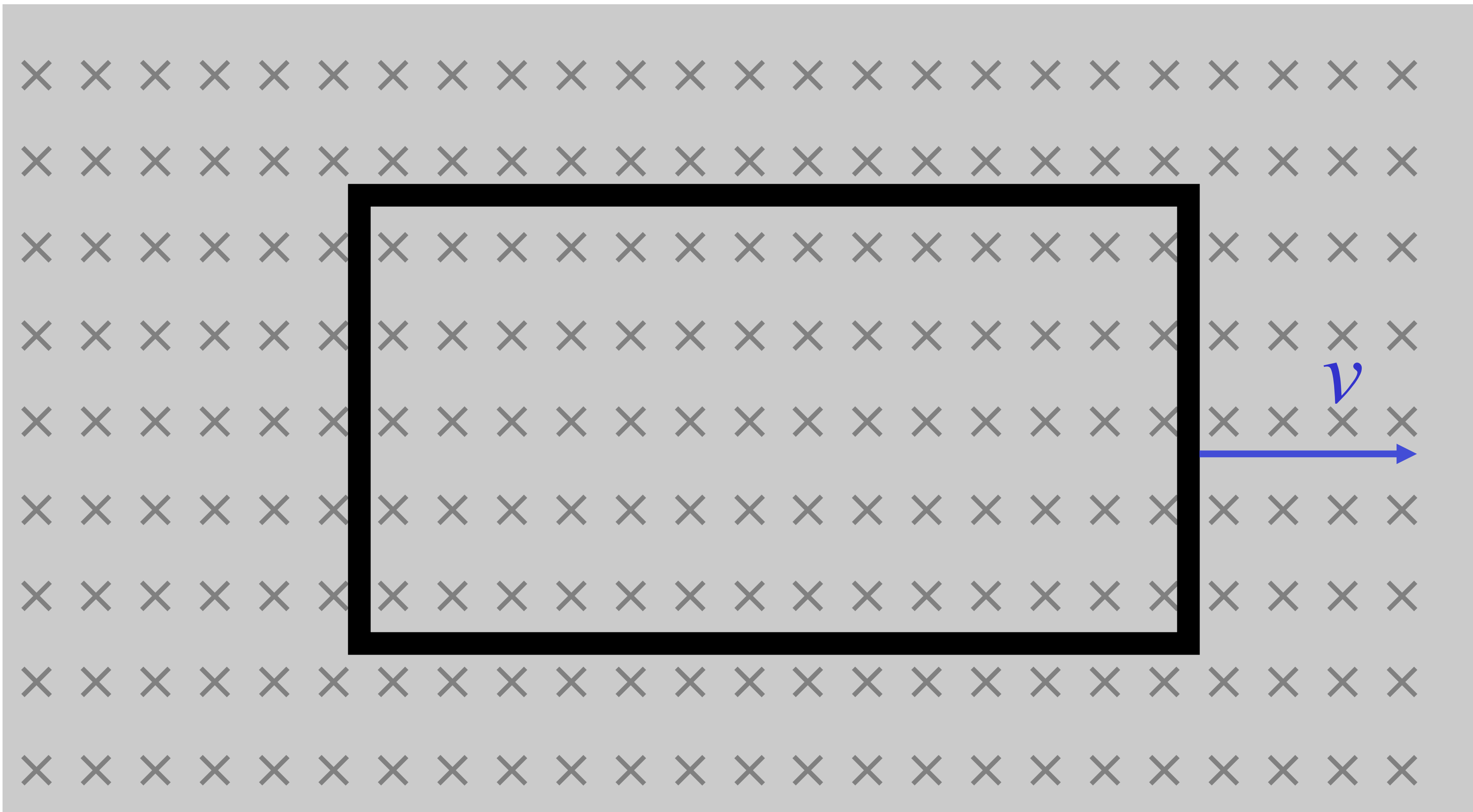
Motional emf

What about this situation?



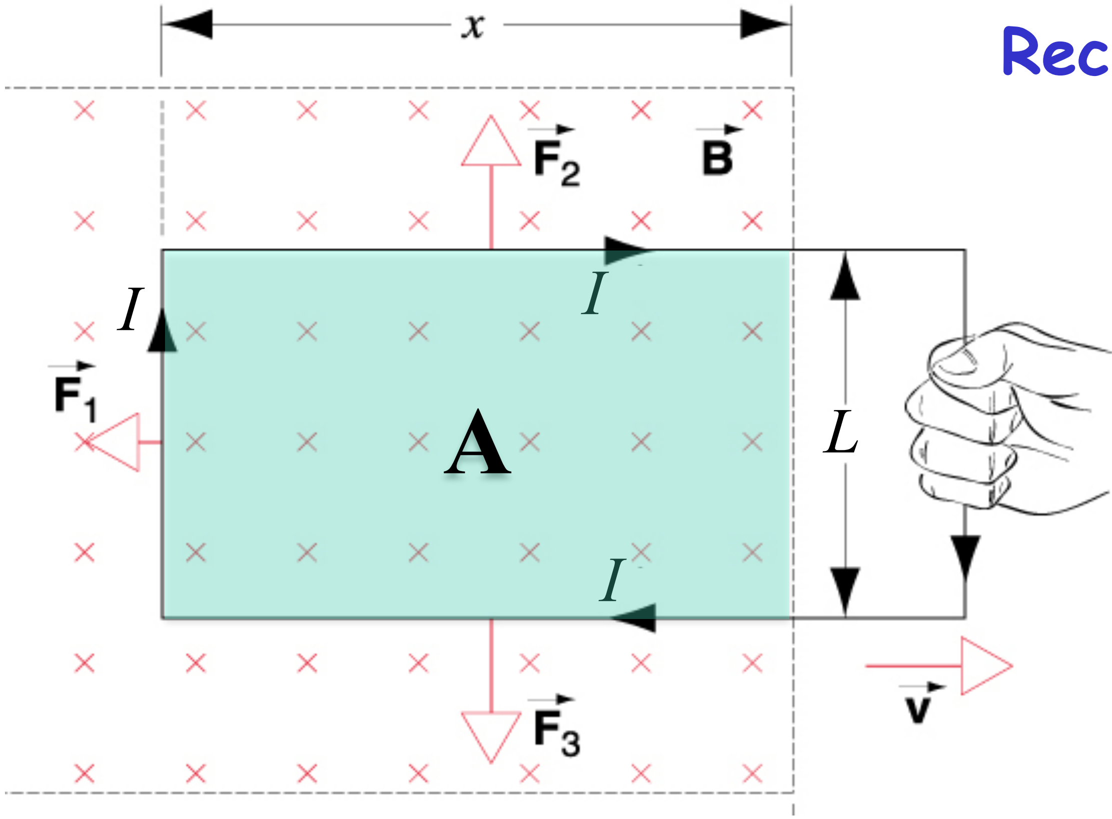
Motional emf

What about this situation?



Is there a motional emf ?

Motional emf and the Lorentz Force Law



Recall Lorentz force:

$$\vec{F} = q\left(\vec{v} \times \vec{B}\right)$$

$$\Rightarrow \left|F\right| = BIL$$

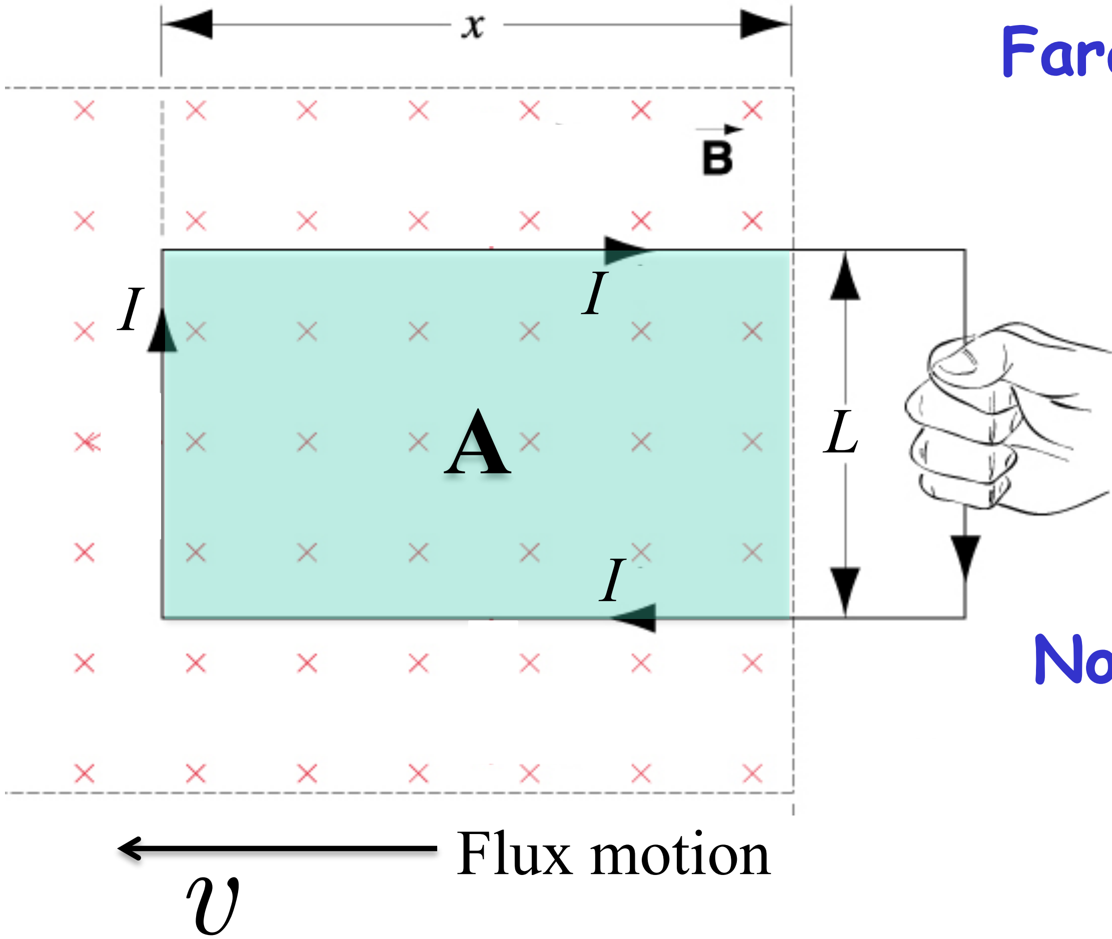
$$P = Fv = \varepsilon I = \left(BIL\right)v$$

$$\Rightarrow \varepsilon = BLv$$

$$v = -\frac{dx}{dt} \qquad \Rightarrow \varepsilon = -BL\frac{dx}{dt} = -\frac{d}{dt}\left(BLx\right) = -\frac{d}{dt}\left(BA\right) = -\frac{d\Phi_B}{dt}$$

- Thus, Lorentz force law and Faraday's law apparently the same…
- What is magnet moves instead of the current loop?

Motional emf and the Lorentz Force Law



Faraday's law:

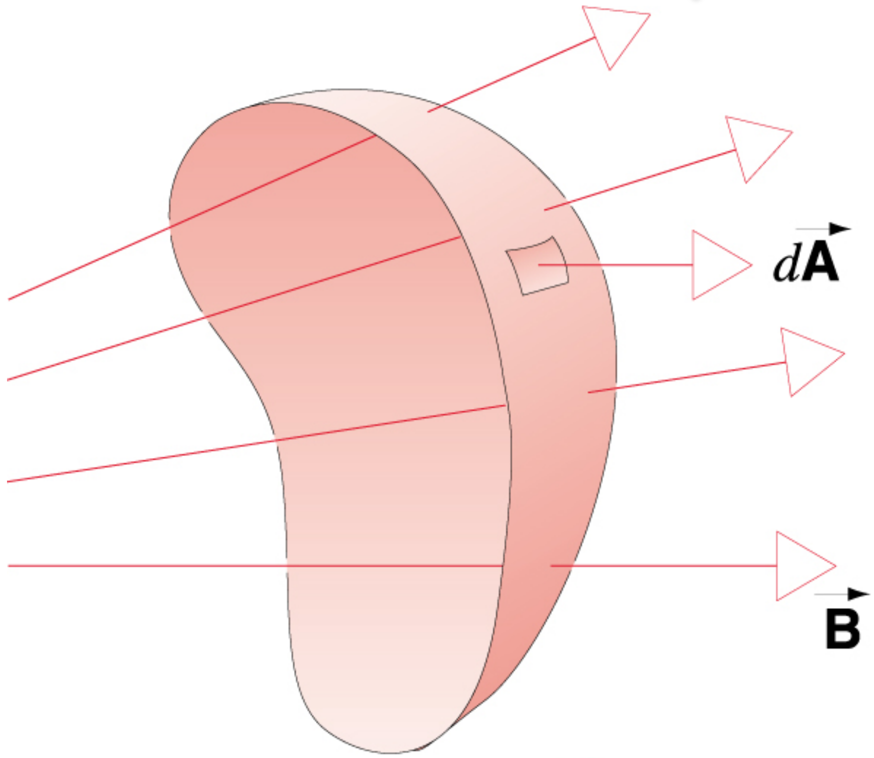
$$\Phi_B = BA = BLx$$

$$\left|\varepsilon\right| = \left|\frac{d\Phi_B}{dt}\right| = BLv$$

No surprise - same result!

An example of relativistic invariance

Faraday's and Lenz' laws



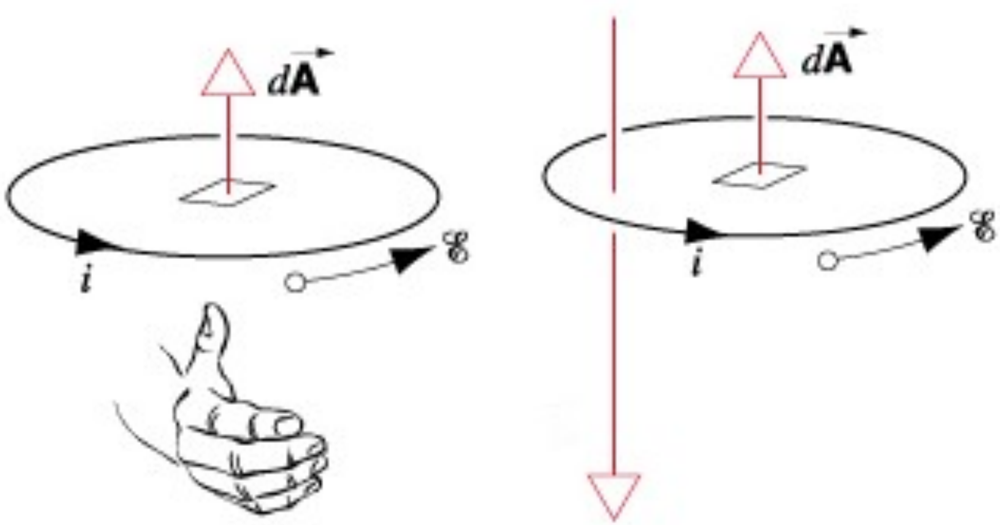
Magnetic flux:

$$\Phi_B = \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = BA\cos\theta$$

$$1 \text{ weber} = 1 \text{ tesla} \cdot \text{meter}^2$$

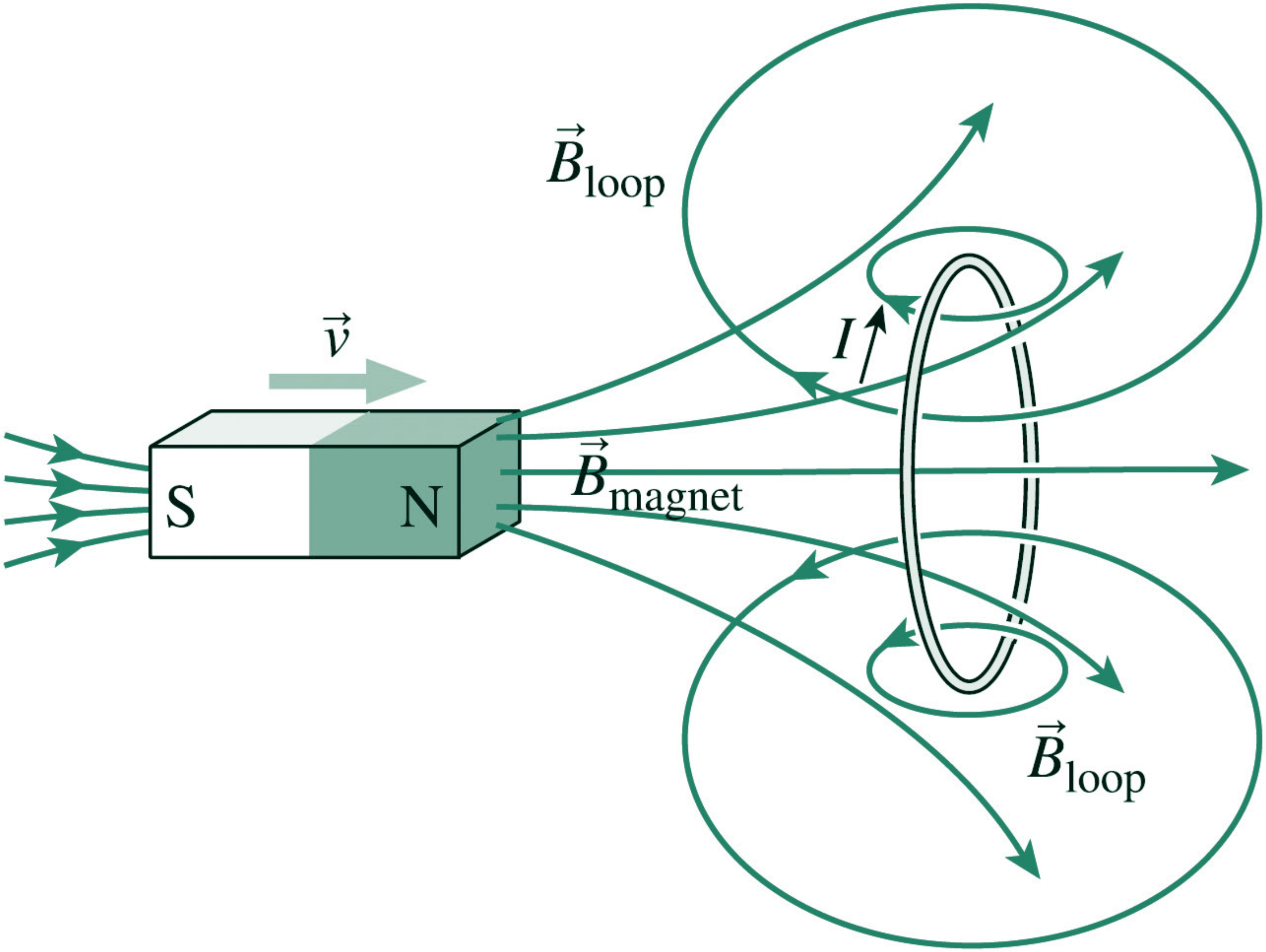
Faraday's law:

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

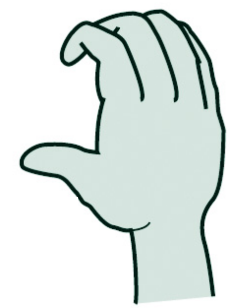


- Induced emf drives a current which opposes the change in the applied magnetic field.
- This required on basis of energy conservation.

Faraday's and Lenz' laws

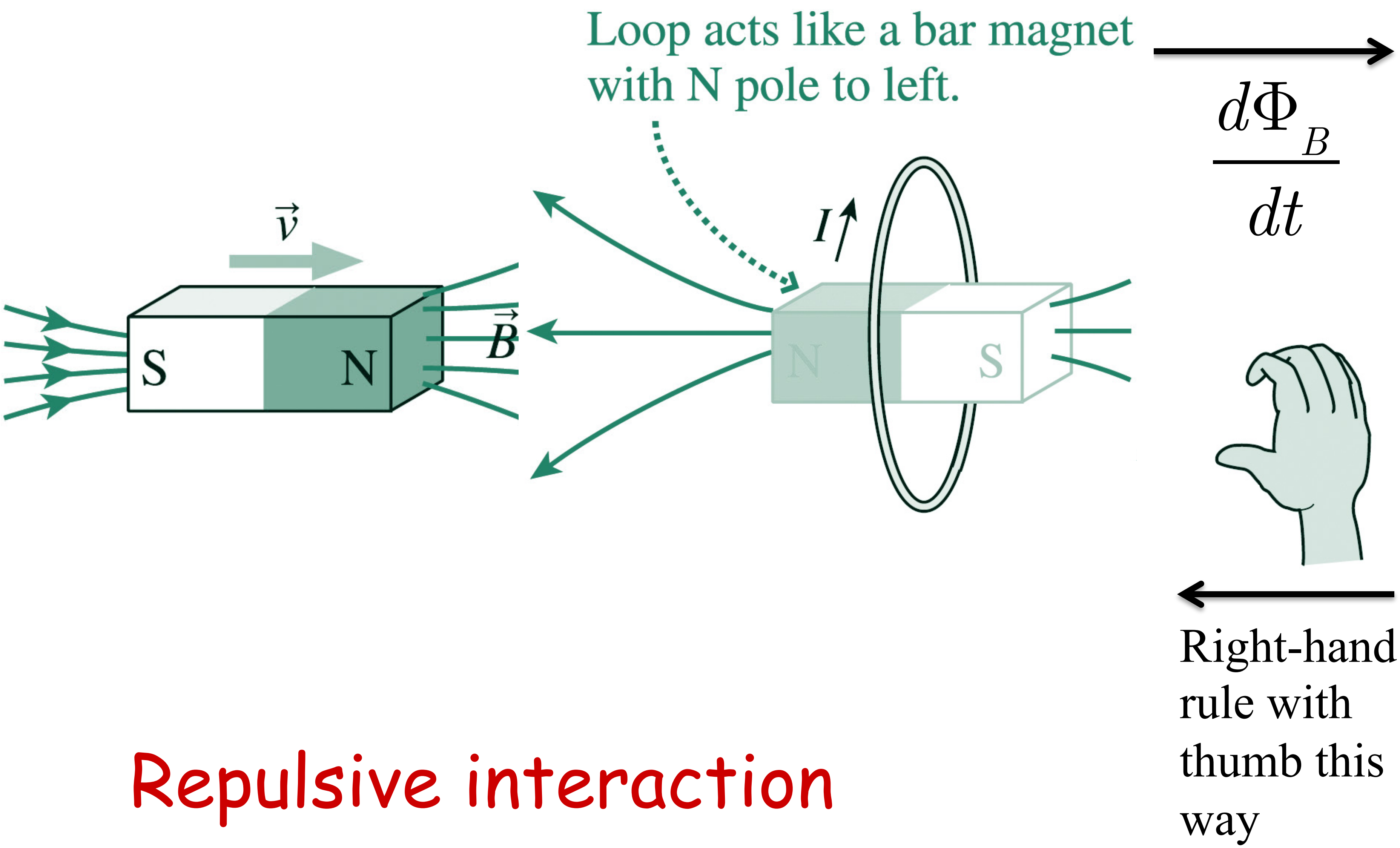


$$\frac{d\Phi_B}{dt}$$



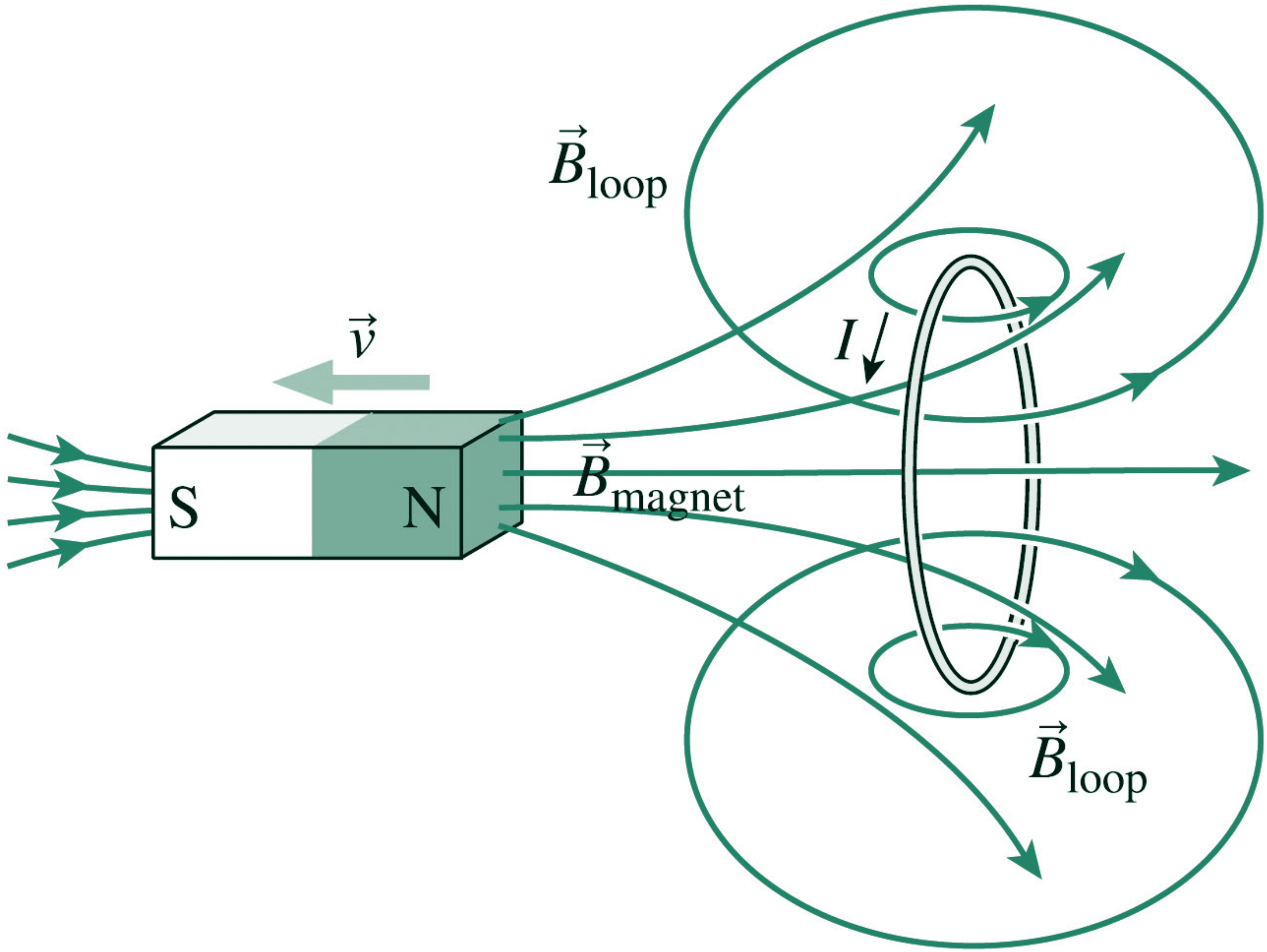
Right-hand rule with thumb this way

Faraday's and Lenz' laws

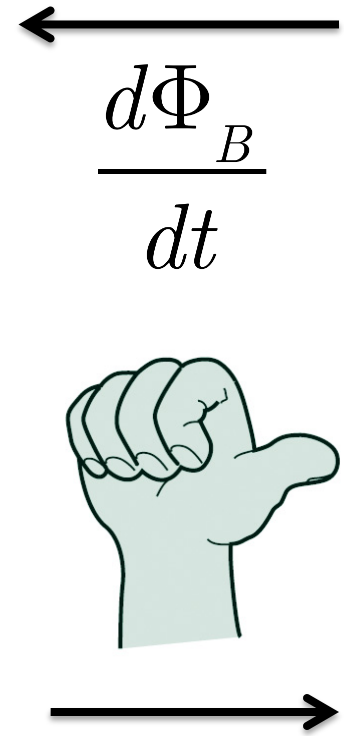


Repulsive interaction

Faraday's and Lenz' laws

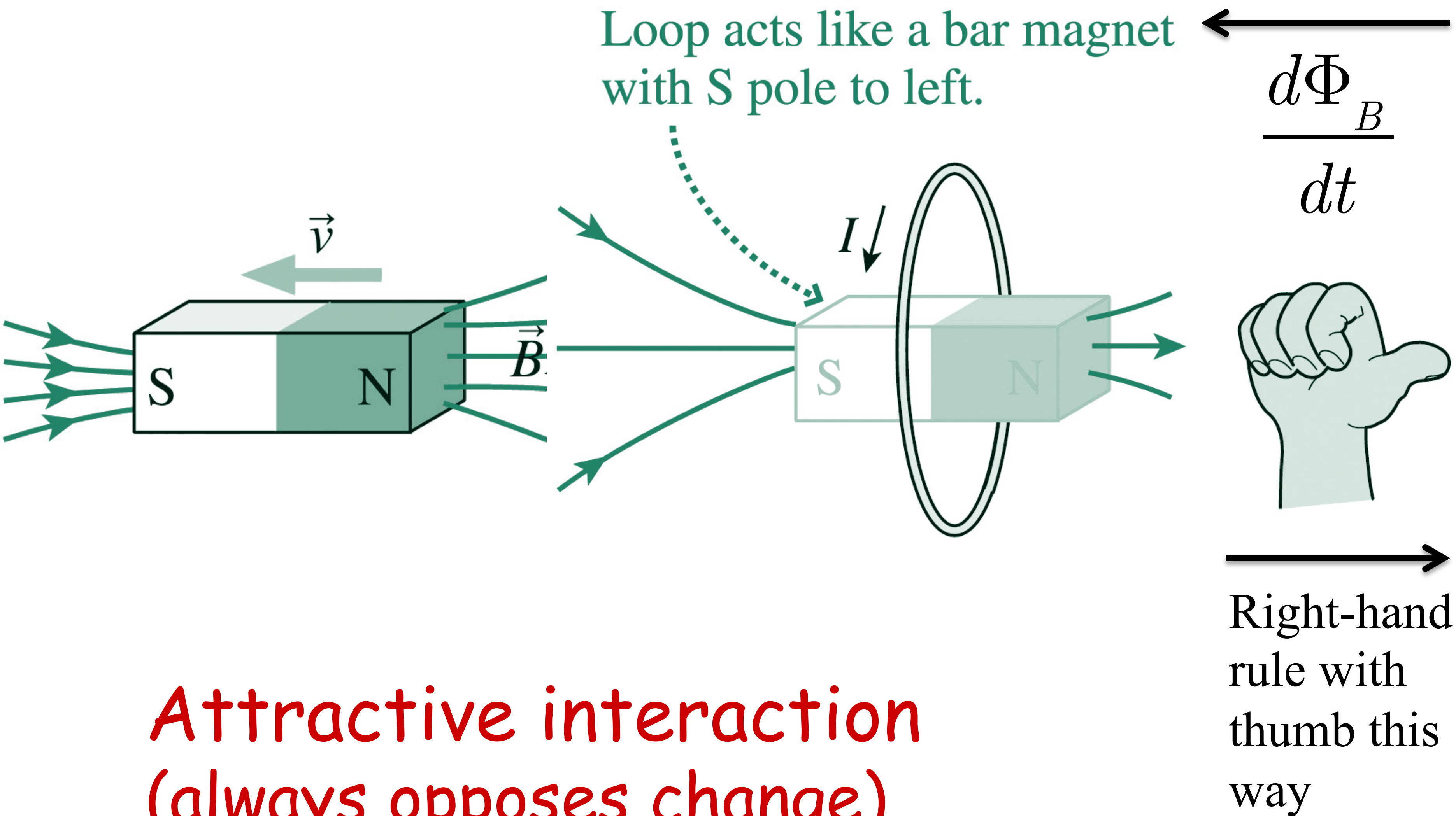


$$\frac{d\Phi_B}{dt}$$



Right-hand rule with thumb this way

Faraday's and Lenz' laws



Attractive interaction
(always opposes change)