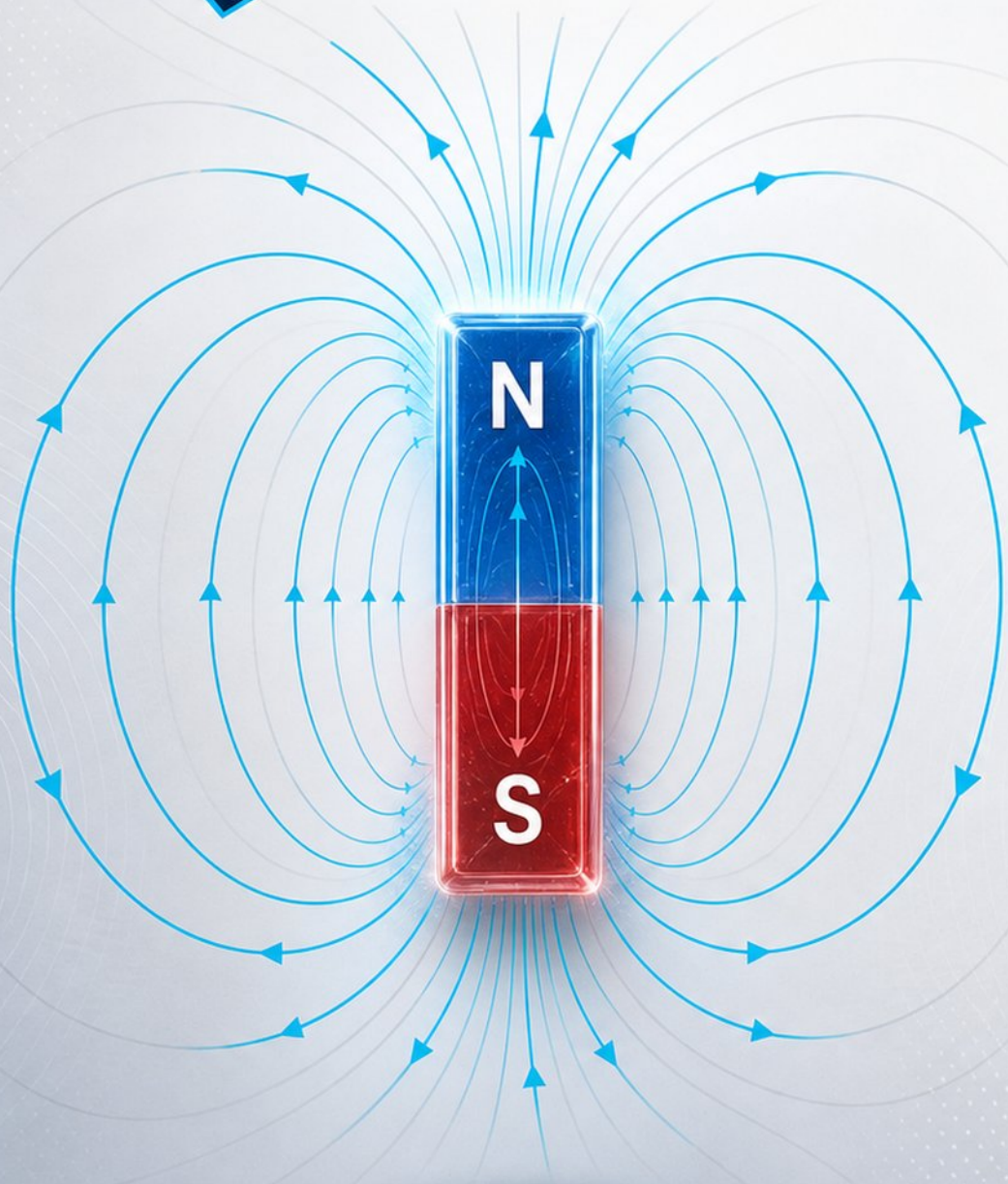
Magnetism: Fields, Forces, and Earth

- Visualizing magnetic fields, forces, and Earth's magnetism
- Building intuition with field lines before using equations
- Roadmap: field patterns, forces, Earth's magnetosphere, hands-on models

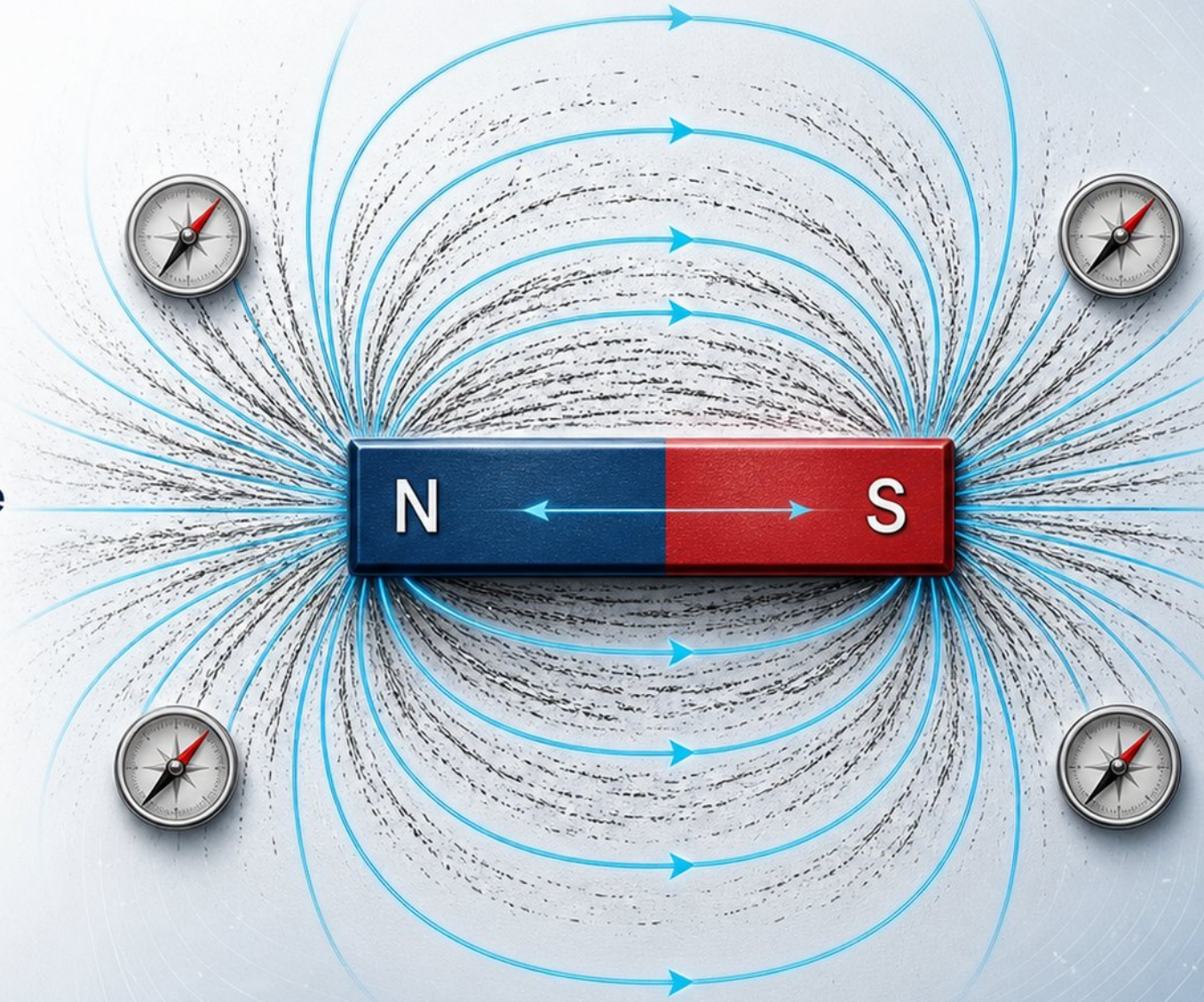
What Is a Magnetic Field?



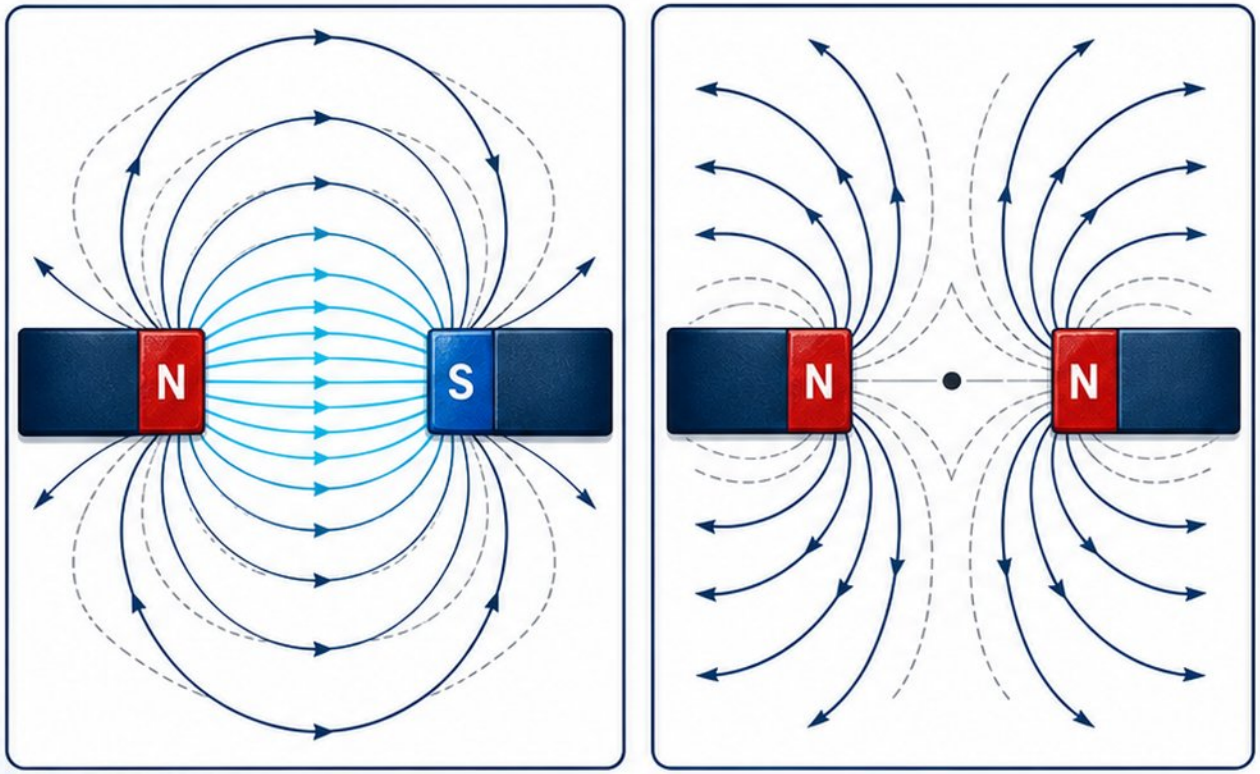
- Region of influence surrounding a magnet or moving charges
- Vector field: direction and strength at every point
- Field lines show direction (compass needle) and strength (line density)
- Lines form closed loops; they never cross

Mapping the Invisible: Single Bar Magnet

- Classic dipole pattern: lines exit North, curve, and enter South
- Iron filings or compass reveal the 3D field shape
- Arrows point North to South; line density shows strength
- Always close loops inside the magnet; never cross lines



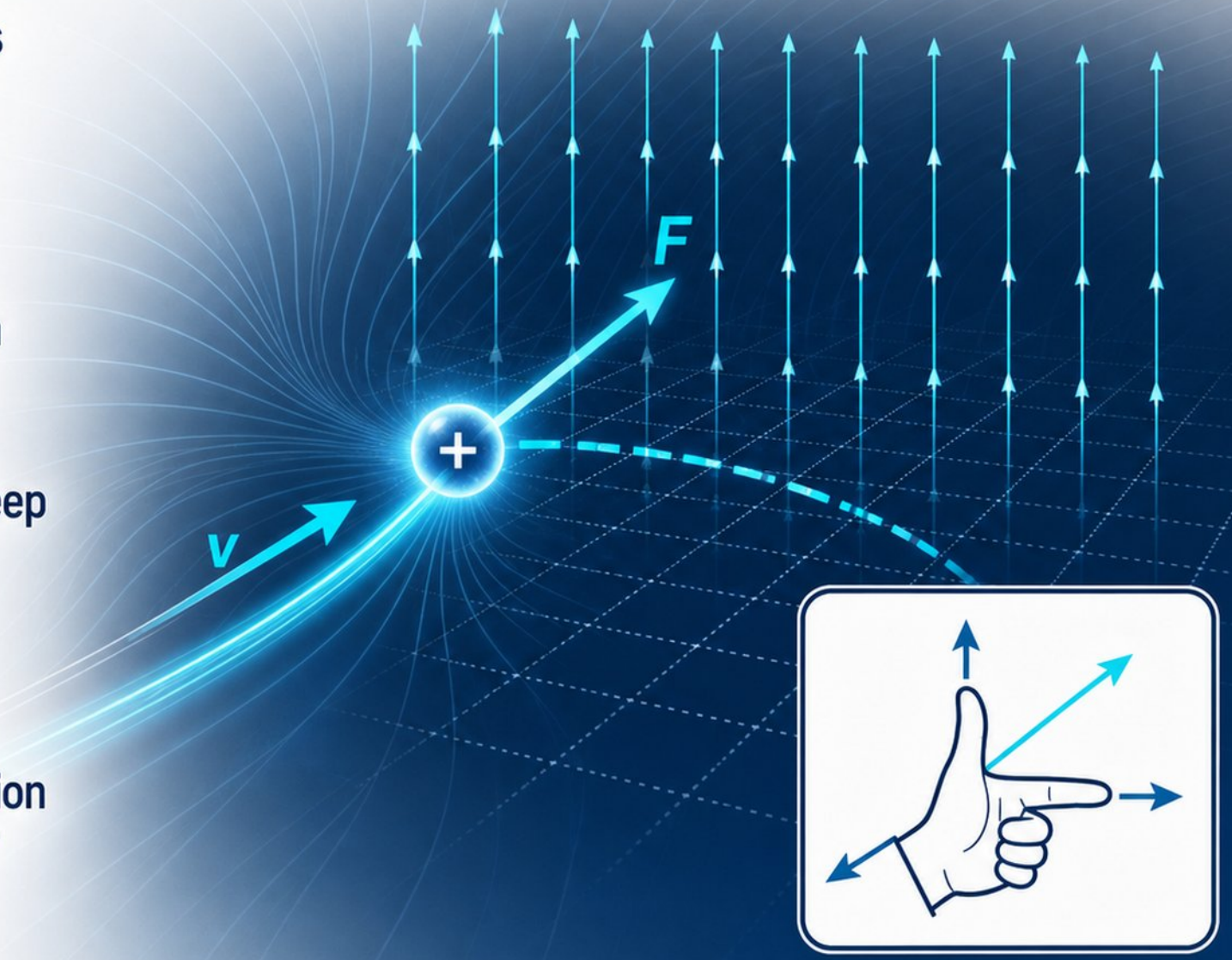
Field Patterns Between Two Magnets



- Attraction (N–S): field lines connect directly, concentrating between poles
- Repulsion (N–N or S–S): lines bend away, forming a neutral point
- Superposition: total field equals the sum of each magnet's field
- Attraction vs. repulsion is visible purely through field line shapes

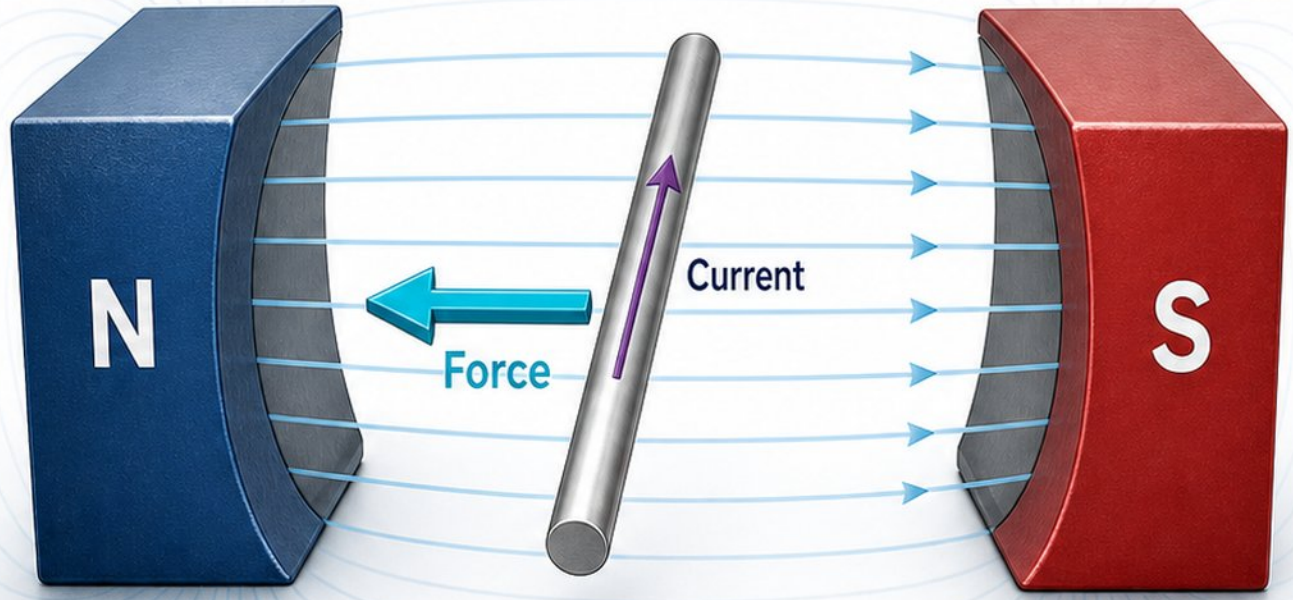
How Magnetic Forces Act on Moving Charges

- “Magnetic force acts only on moving charged particles”
- “Lorentz force is perpendicular to both velocity and field”
- “Right-hand rule: sweep v toward B, thumb gives F for positive charge”
- “Reverse force direction for negative charges”



Force on a Current-Carrying Wire

- Current in a wire is a stream of moving charges
- Magnetic field exerts a force on the entire wire
- Right-hand rule: thumb = current, fingers = field, palm = force
- Force strongest when current is perpendicular to field
- Zero force when current is parallel to the field
- This principle is the basis of electric motors

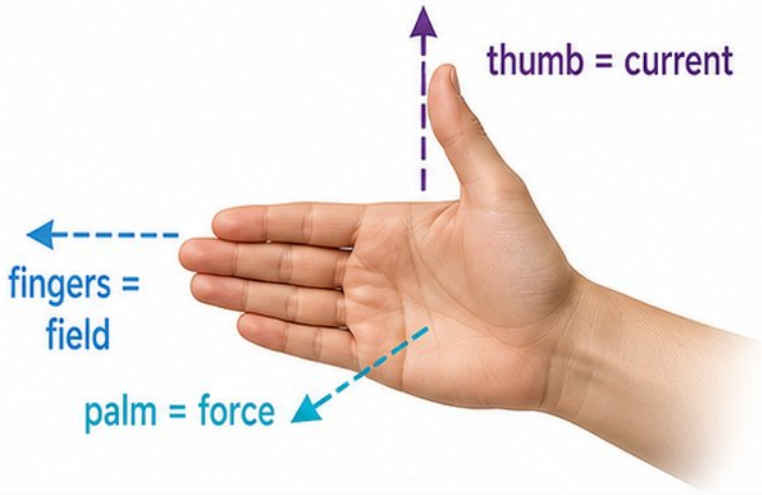


Right-hand rule:

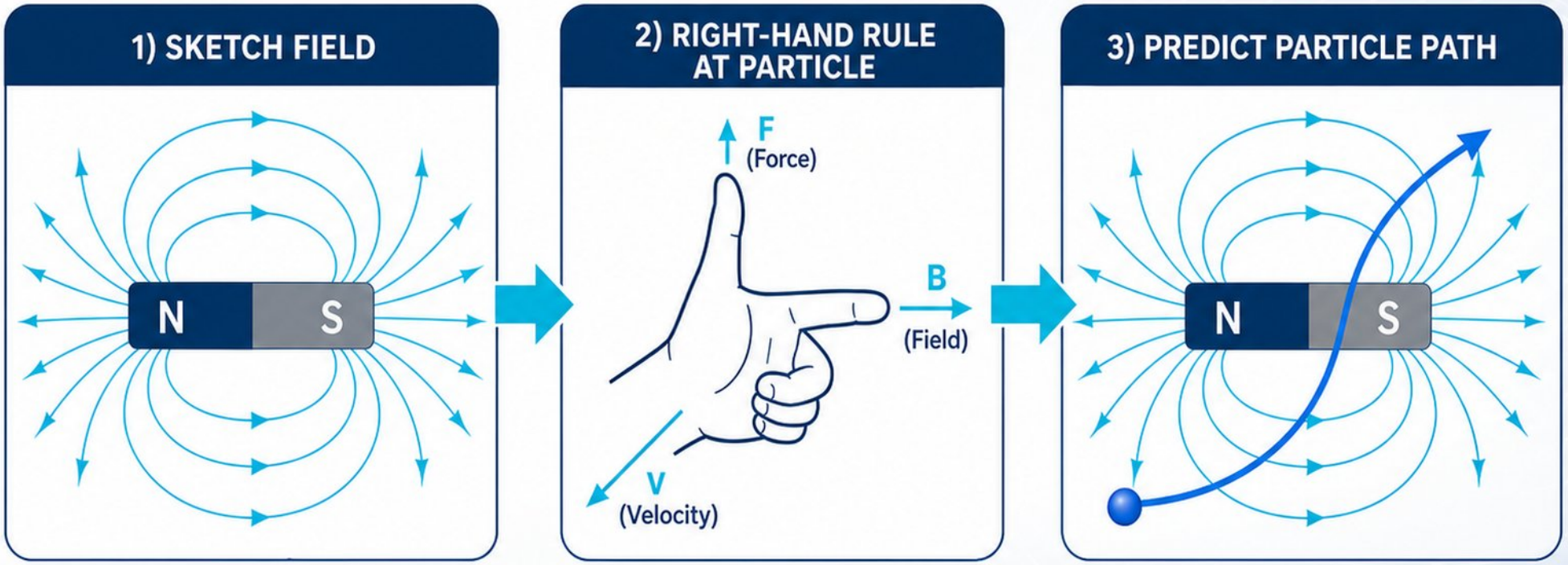
thumb = current

fingers = field

palm = force

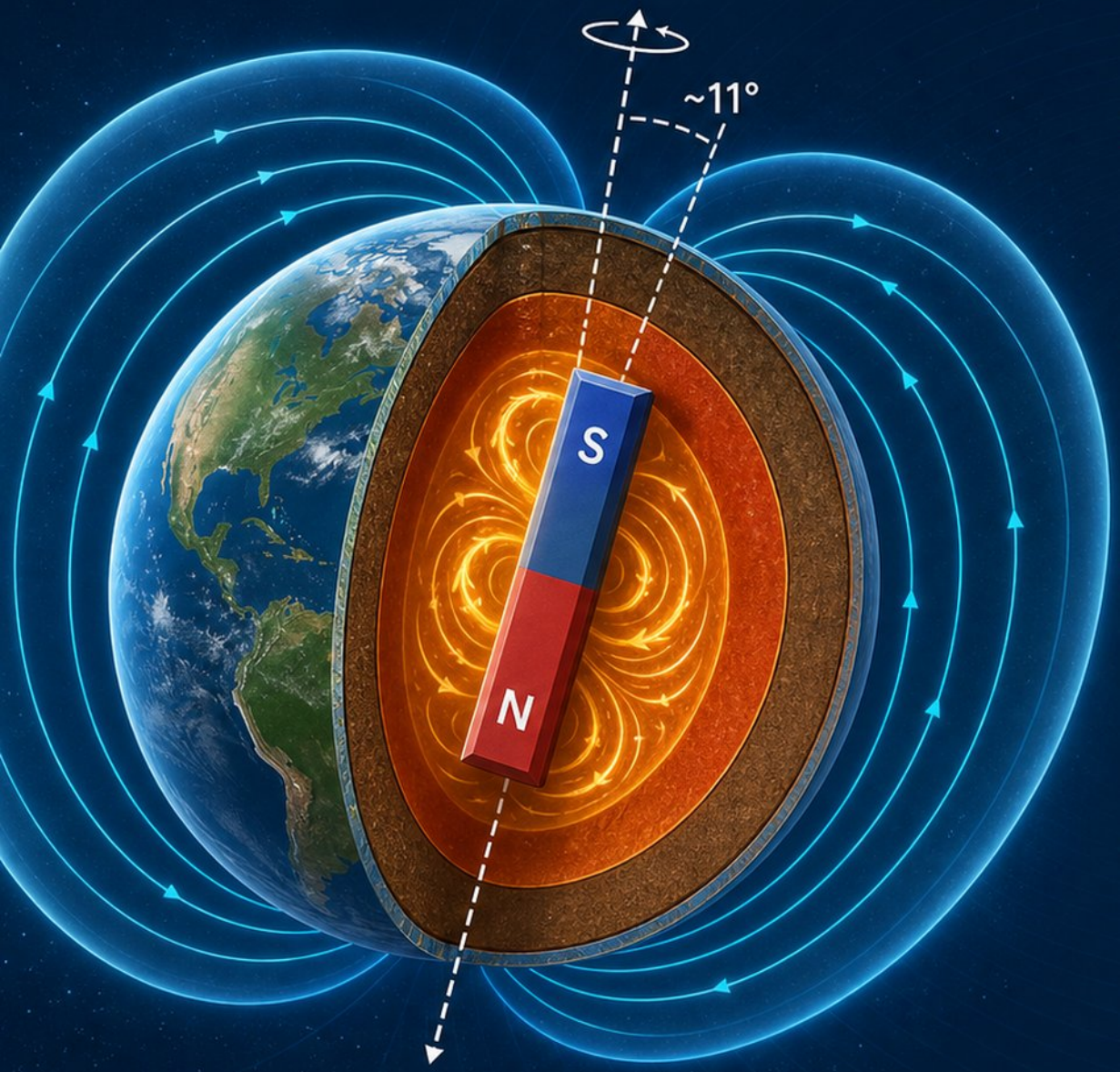


Translating Field Patterns into Force Predictions



- Field lines show push direction for a North pole
- Magnets feel force from stronger to weaker field regions
- Zero magnetic force when moving parallel to field lines
- Visual strategy: sketch field, apply right-hand rule at particle

Earth as a Giant Magnet



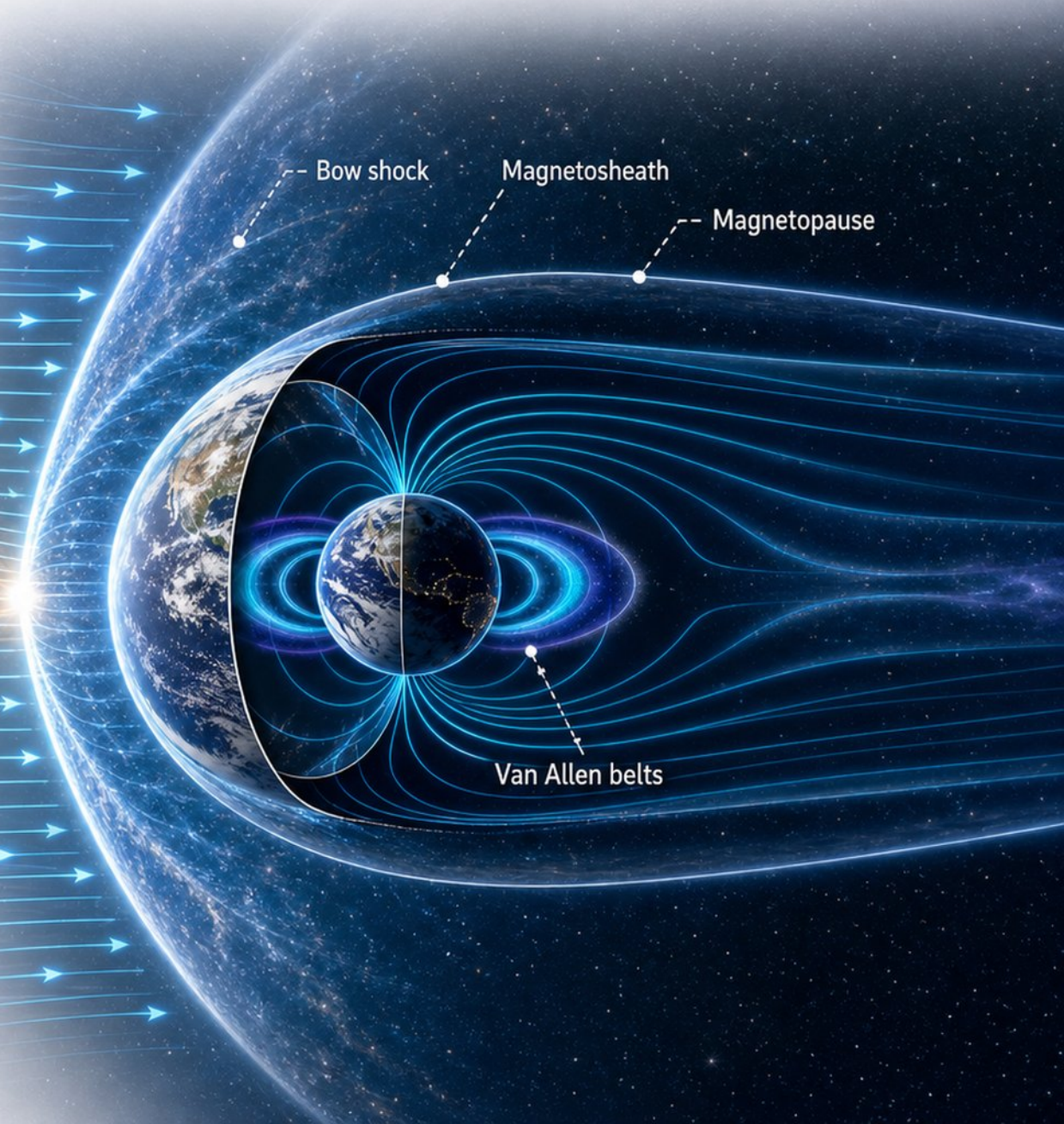
- Earth's field approximates a tilted bar magnet, inclined ~11° from the rotation axis
- Generated by the geodynamo: swirling liquid iron in the outer core
- Magnetic South Pole lies near the geographic North Pole, attracting a compass's North end
- The magnetosphere is the region of space dominated by Earth's field, shielding the planet

The Moving Magnetic Poles

- Magnetic poles are not fixed; they wander continuously over time
- The North Magnetic Pole currently drifts toward Siberia at ~36 km/year
- Movement accelerated historically but has recently decelerated
- Tracked by the World Magnetic Model for navigation accuracy
- Drifting pole alters compass declination over time

The Magnetosphere: Our Shield in Space

- Solar wind compresses dayside, stretches nightside into a long magnetotail
- Key structures: bow shock, magnetosheath, magnetopause, Van Allen belts
- Deflects most solar particles, shielding atmosphere and life from radiation
- Particles funneled to poles set the stage for auroras



Evidence of Earth’s Magnetism: The Compass

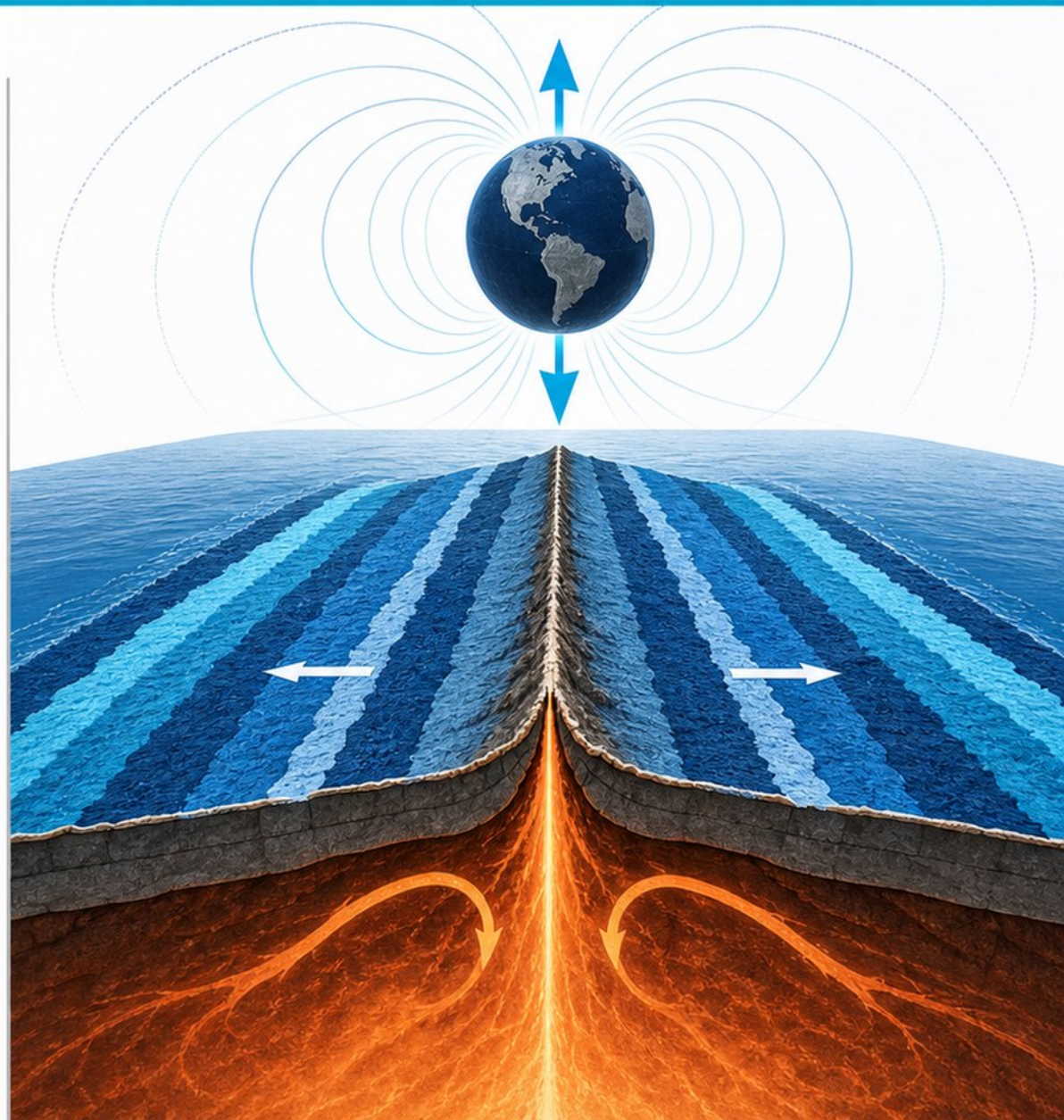
- A compass needle is a tiny bar magnet aligning with Earth's field lines
- Magnetic declination: horizontal angle between true north and magnetic north
- Magnetic inclination (dip angle): angle the field makes with the surface
- Near the poles, the field is nearly vertical; at the equator, nearly horizontal
- Compass behavior gives a direct, tactile map of local field direction

Auroras: The Light of the Field

- Solar wind particles spiral down field lines into the atmosphere
- Collisions with atmospheric gases produce green, red, purple, or blue light
- Auroral ovals form around magnetic poles, not geographic poles
- Auroras are visible proof of the magnetosphere channeling particles

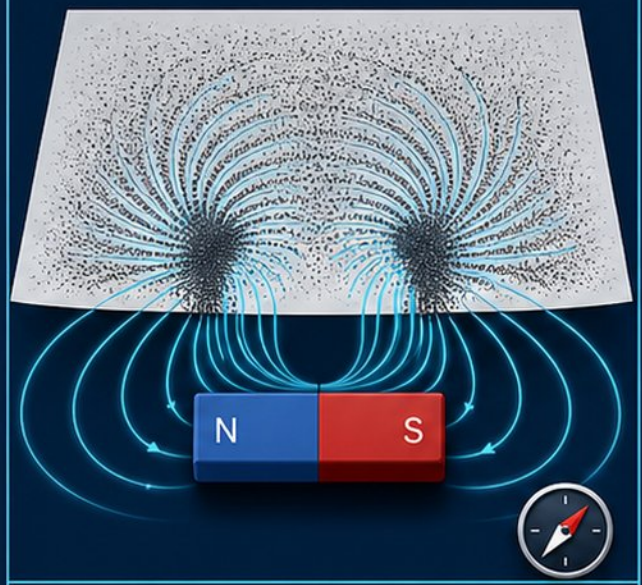
Paleomagnetism: Earth's Magnetic Memory

- Magnetic minerals in rocks lock in Earth's field direction at formation
- Ocean floor magnetic stripes reveal symmetrical polarity reversals
- Seafloor spreading confirmed by matching stripe patterns on both sides
- Last full reversal occurred approximately 780,000 years ago
- These records prove the geodynamo has been active for billions of years



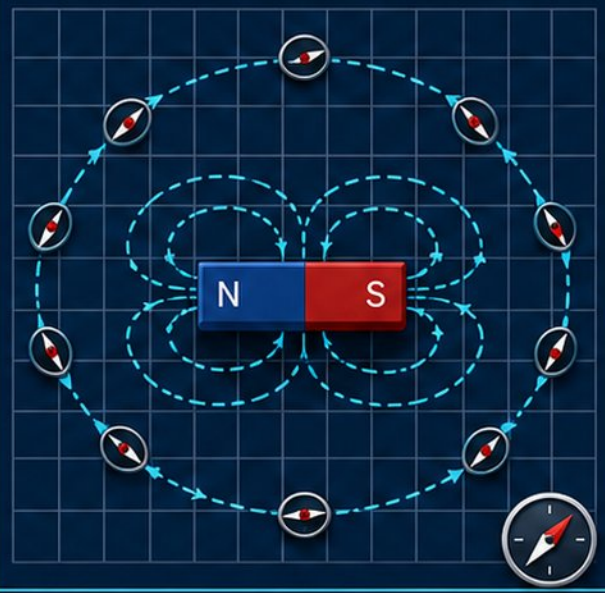
Building Your Visual Model: Hands-On Tools

1. Iron filings



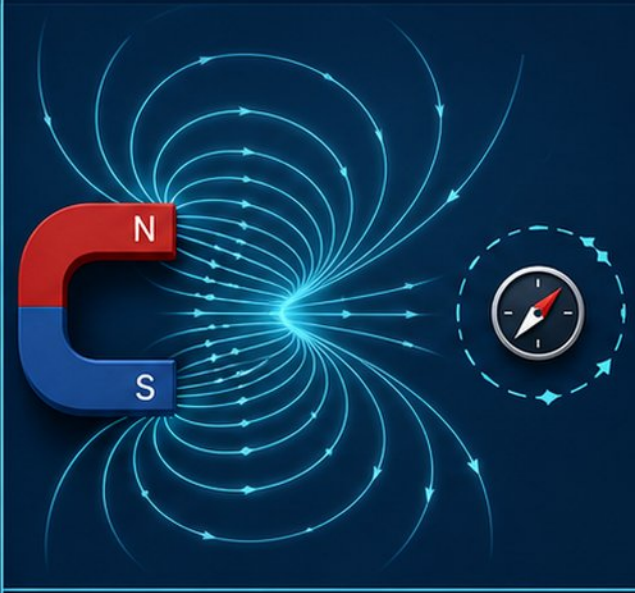
- **Iron filings:** sprinkle on a sheet over a magnet to reveal field lines directly.

2. Compass plotting



- **Compass plotting:** move a small compass in a grid, draw arrows tangent to the needle.

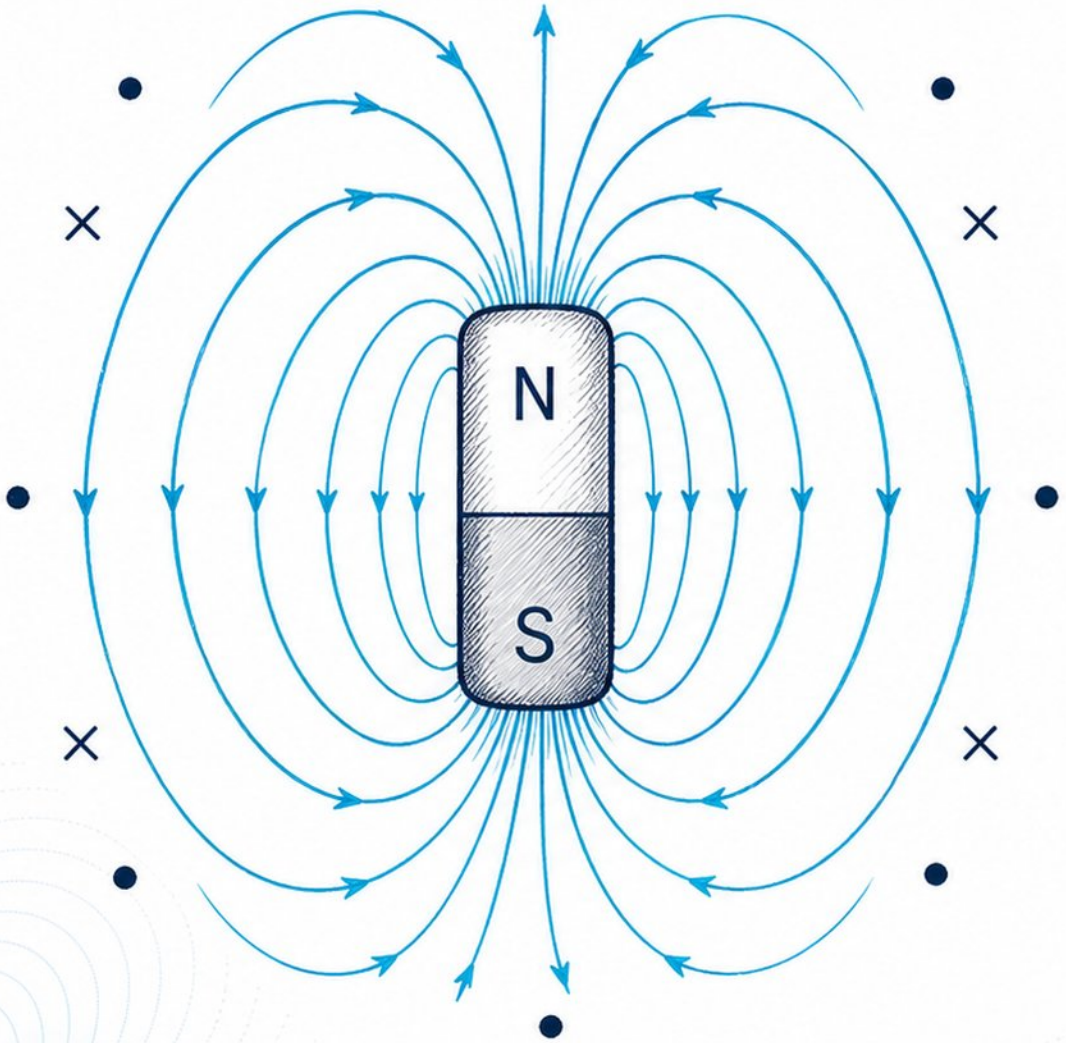
3. PhET simulations



- **PhET simulations:** “Magnets and Electromagnets” and “Magnet and Compass” for interactive exploration.

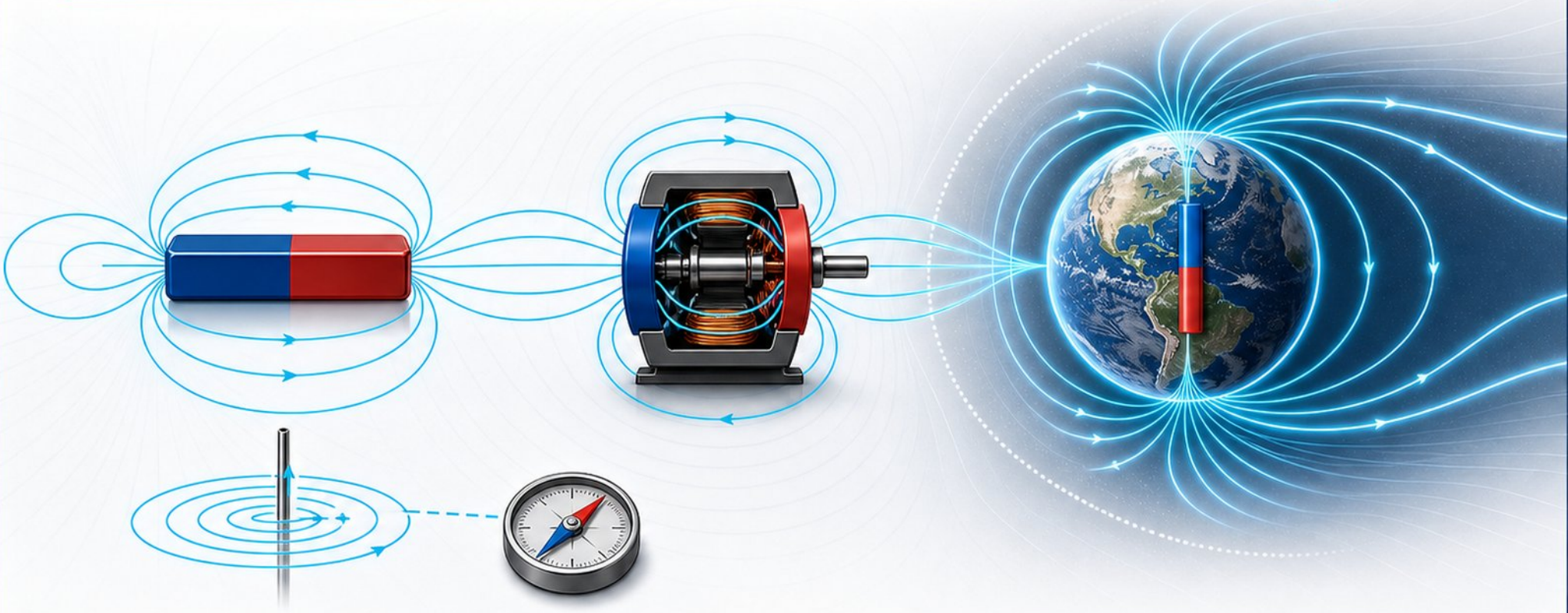
Combine physical tools with digital sims to reinforce the 3D nature of magnetic fields.

Sketching Conventions for 3D Fields



- Add arrows on field lines pointing North to South outside the magnet
- Use closer line spacing to indicate stronger field regions
- Represent out-of-page direction with dots (•), into-page with crosses (×)
- Field lines must form closed, uncrossed loops

A Unified View: Fields, Forces, and Earth



- “Field-line logic connects bar magnets, motors, and the magnetosphere”
- “A compass near a wire feels force from the wire's magnetic field”
- “Field patterns let you predict forces on charges or magnets”
- “The visual model is qualitative; next step is quantifying B (Tesla)”

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