Magnetostatics

Magnetic Fields and Interactions

AP Exam Content: Electricity & Magnetism	
Electrostatics: charge, Coulomb's Law, electric field and potential, Gauss's Law	✓30%
Conductors, Capacitors: capacitance, capacitor types – parallel plate, cylindrical, etc., dielectrics	✓14%
Electric Circuits: current, resistance, power, resistor/battery combinations, RC circuits	✓20%
Magnetic Fields: forces on charges and current-carrying wires, Biot-Savart Law, Ampere's Law	20%
Electromagnetism: induction, Faraday's Law, Lenz's Law, inductance, LR and LC circuits, Maxwell's equations	16%

Magnetostatics

I. Field Basics – units, poles

II. Magnetic Force on Charge
   - Mass Spectrometer
   - Cyclotron

III. Magnetic Force on Current
   - Motors and Meters

IV. Sources of Magnetic Fields
   - Biot-Savart Law
   - Ampere's Law
   - Solenoids

	The student will be able to:	HW:
1	Define and illustrate the basic properties of magnetic fields and permanent magnets: field lines, north and south poles, magnetic compasses, Earth's magnetic field.	1 – 2
2	Solve problems relating magnetic force to the motion of a charged particle through a magnetic field, such as that found in a mass spectrometer.	3 – 10
3	Solve problems involving forces on a current carrying wire in a magnetic field and torque on a current carrying loop of wire in a magnetic field, such as that found in a motor.	11 – 18
4	State and apply the Biot-Savart Law and solve such problems that relate a magnetic field to the current that produced it.	19 – 24
5	State and apply Ampere's Law and Gauss's Law for magnetic fields and solve related problems such as those involving parallel wires, solenoids, and toroids.	25 – 40

Magnetic Field

- A magnetic field affects and is generated by objects with magnetic properties – such as permanent magnets and moving charges.
- The direction of the field is defined as pointing the same as a compass would point.
- Magnetic field strength is measured in SI units of tesla (T) or gauss (G).

Magnetic Field Units

1 tesla = 1 newton per meter per ampere

$$1\,\mathrm{T} = 1\,\frac{\mathrm{N}}{\mathrm{m}\cdot\mathrm{A}}$$

1 gauss = 1 ten thousandth of 1 tesla

$$10^4\ \mathrm{G} = 1\ \mathrm{T}$$

Magnetic Field

- Notice the similarity of the tesla's units (N/mA) to those of electric fields (N/C) and gravitational fields (N/kg).
- A typical permanent magnet has field strength of a few millitesla. One tesla is a very, very strong magnetic field (such as found in an MRI machine).
- At its surface the Earth's magnetic field has magnitude about 0.5 gauss or 50 μT.

Magnetic Poles

- A magnet that is free to rotate will align with the Earth's magnetic field.
- The side or end facing geographic north is called the "North pole" of the magnet (the opposite end is the "South pole").
- When two magnets interact, like poles repel and opposite poles attract.

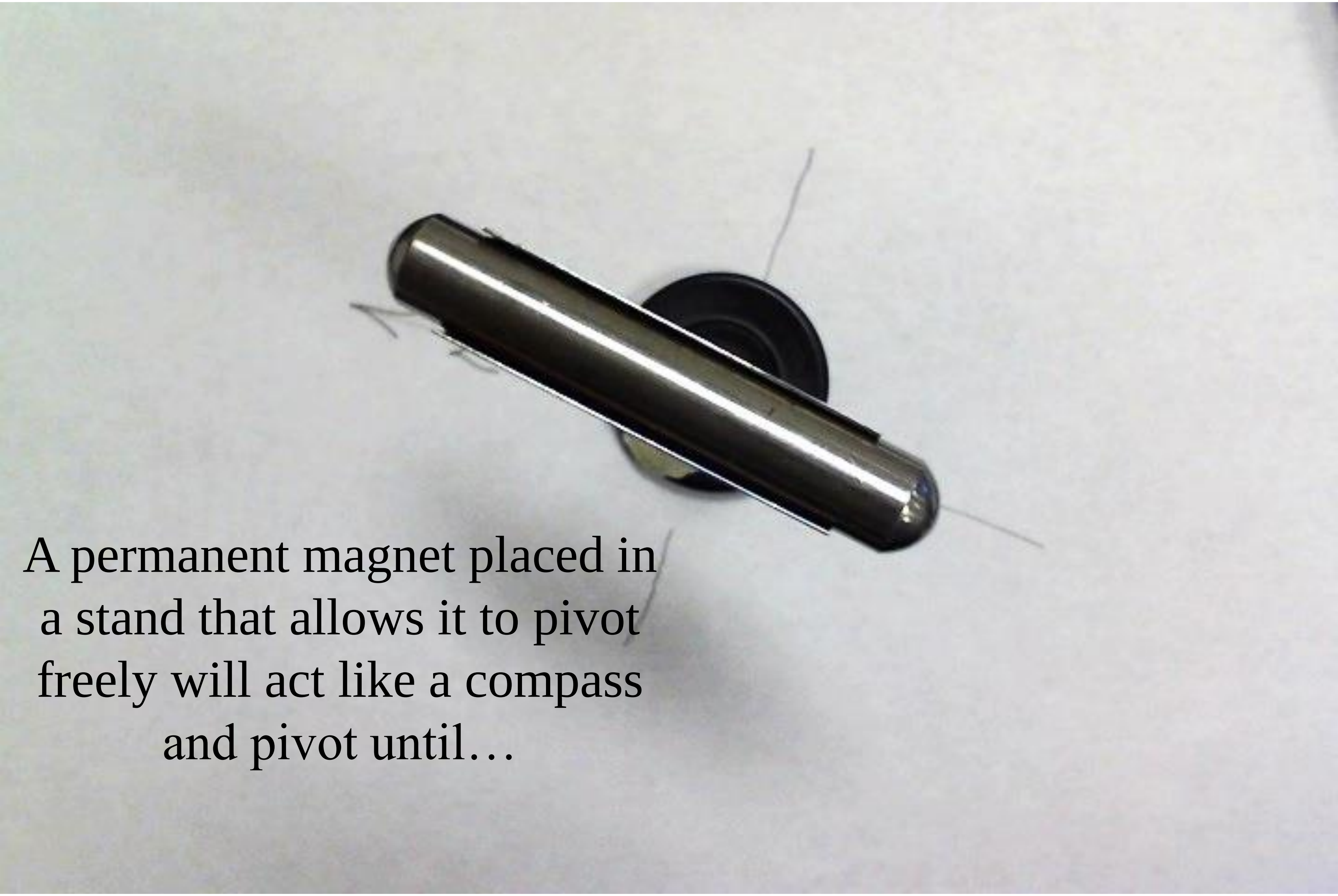
Magnetic Field Lines

- Field lines are drawn such that a compass would point tangent to the line.
- Magnetic field lines will radiate away from a North pole and converge on a South pole.

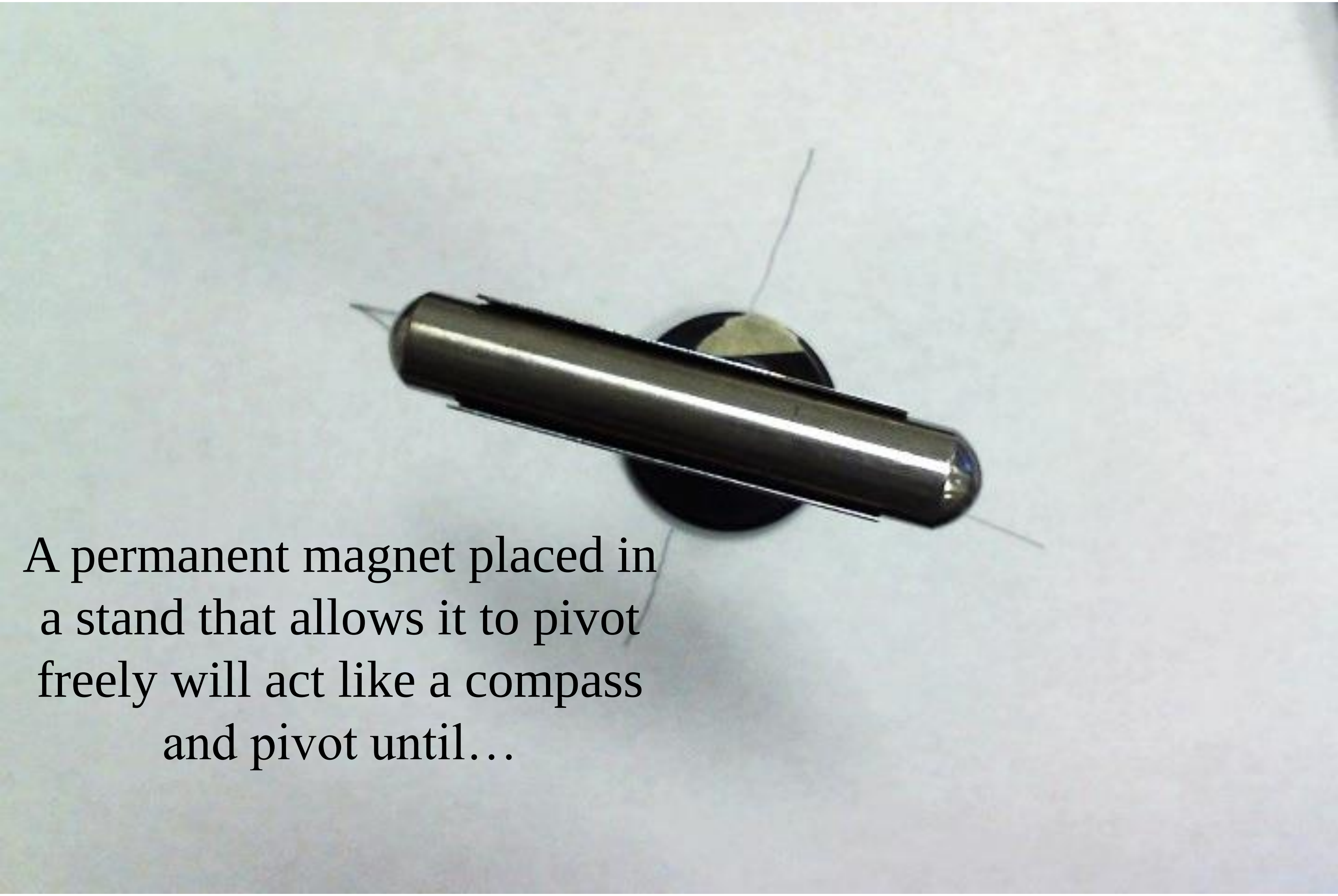
Mini-Lab: Magnetic Poles & Field

1. Center the magnet on the stand so that it can rotate freely and observe which end orients toward the north corner of the room. Mark this end with a small piece of tape. Which pole of the magnet is this? Confirm with another group's magnet that like poles repel and opposite poles attract.
2. Place the magnet at rest on a piece of paper. Use the compass to map the field at various positions all around the magnet. At each location draw an arrow in the direction the compass points.
3. Use your map of arrows as a guide to draw four continuous field lines connecting to each pole of the magnet.


N



A permanent magnet placed in a stand that allows it to pivot freely will act like a compass and pivot until…



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…one end can be identified as the north pole of the magnet – simply the side of the magnet that faces geographic north.

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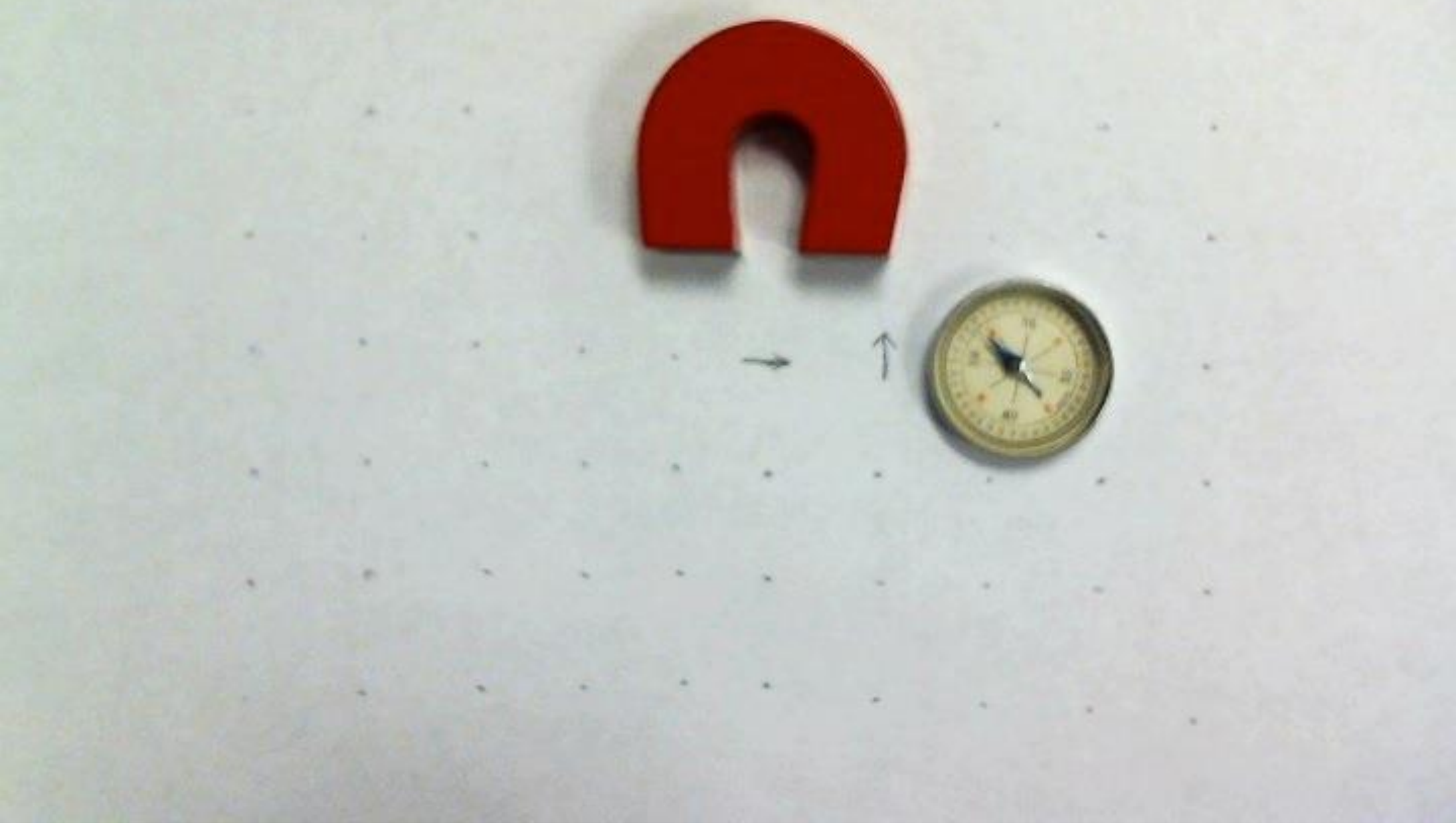

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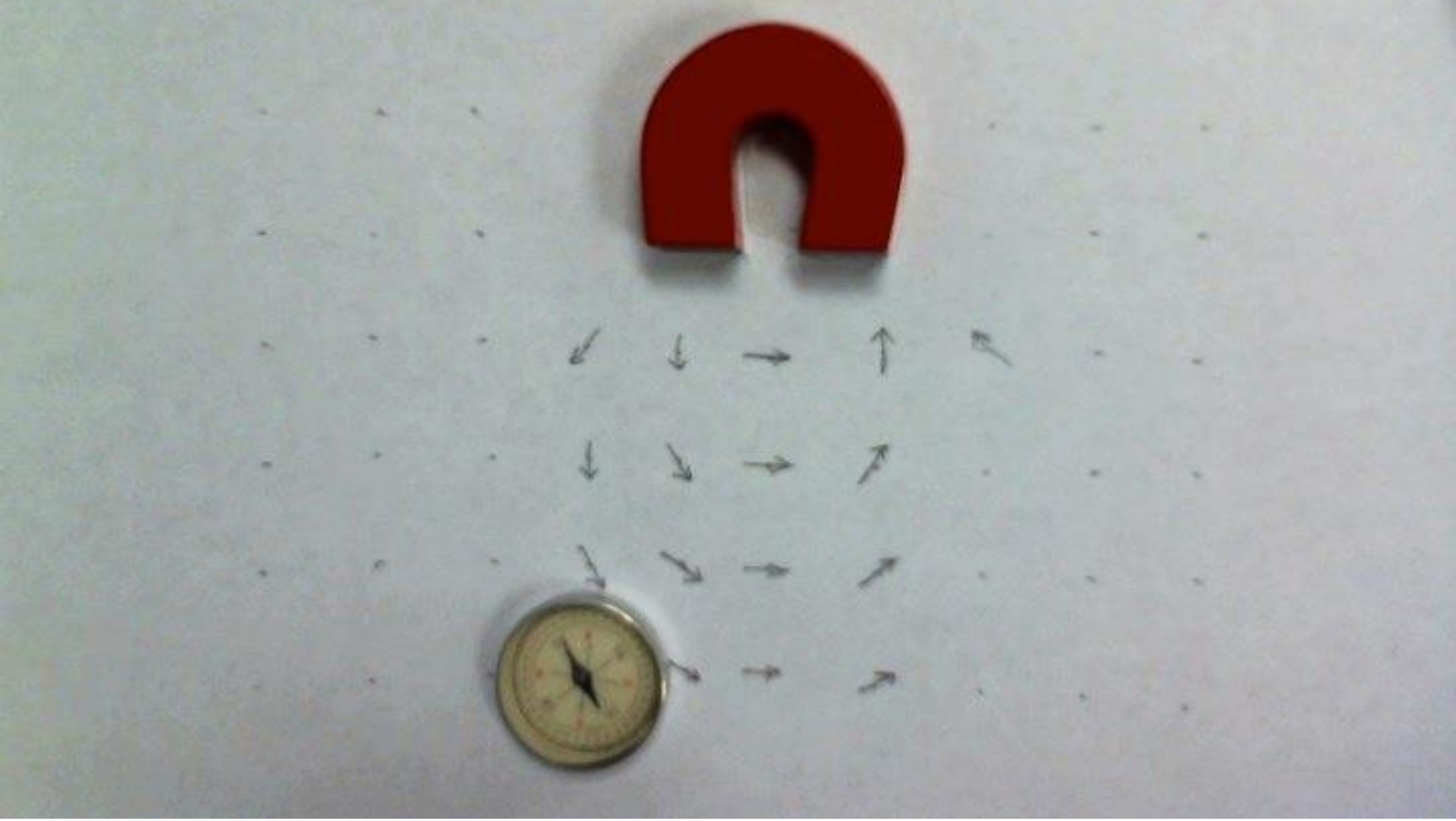

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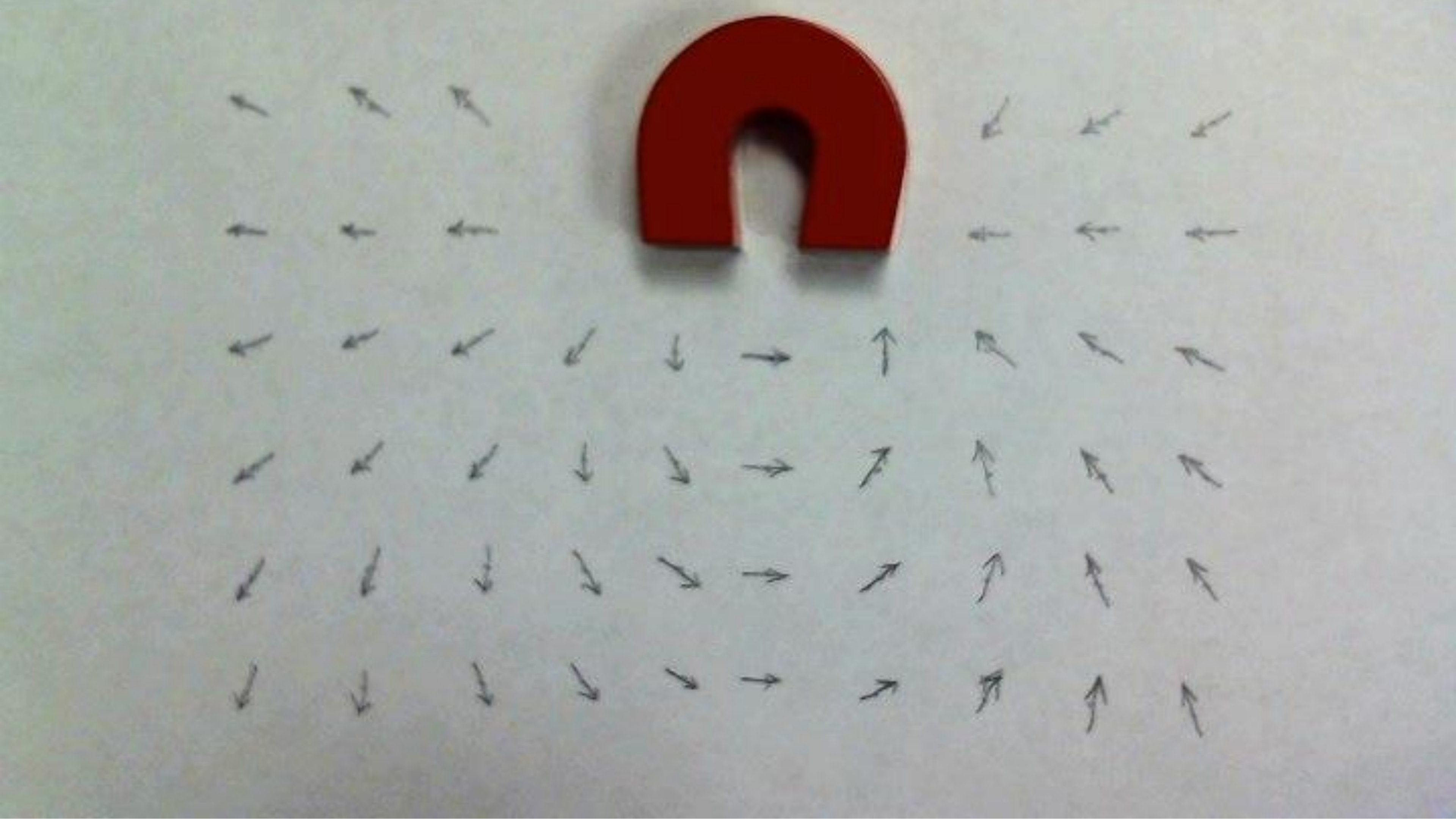

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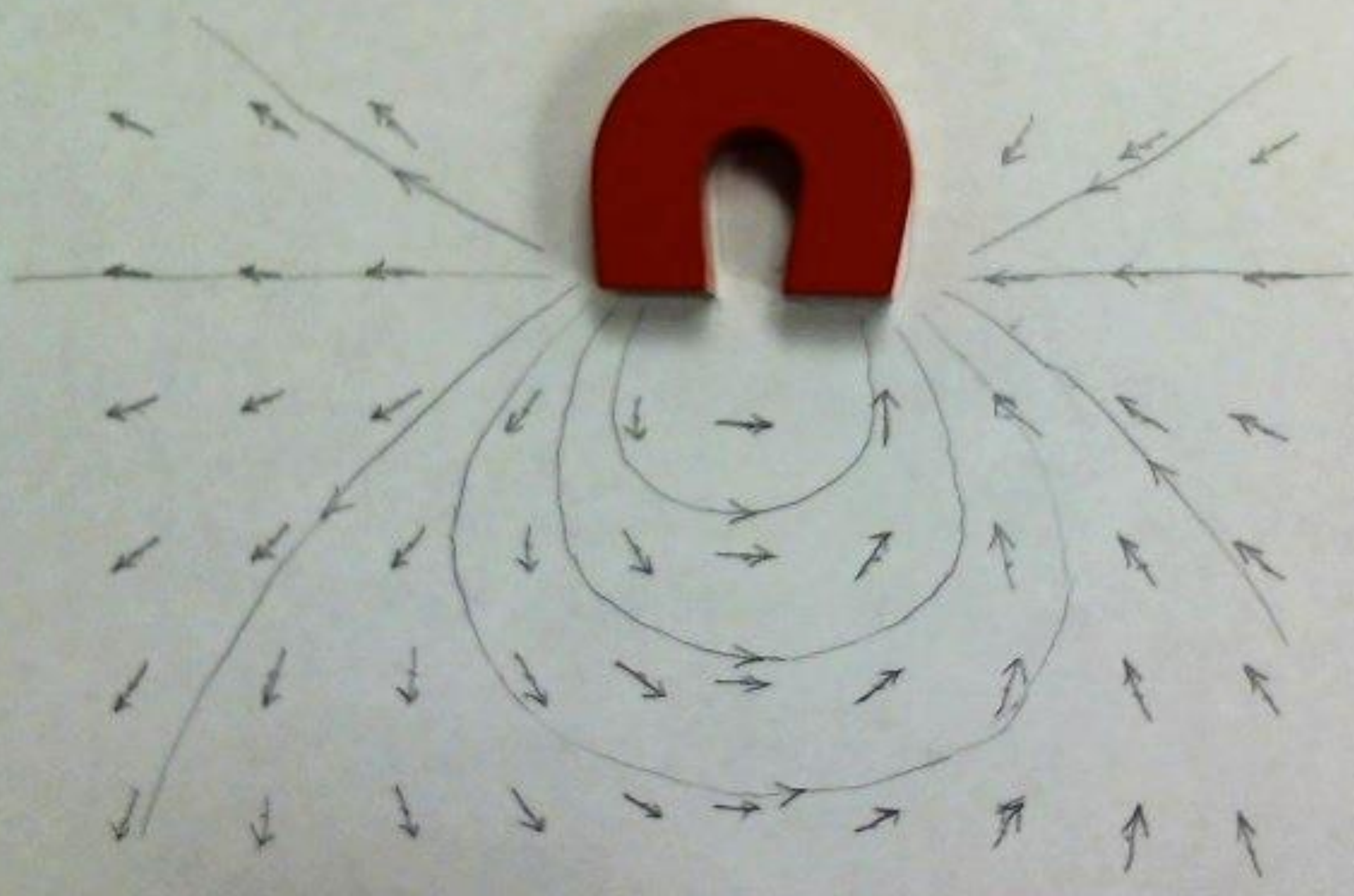
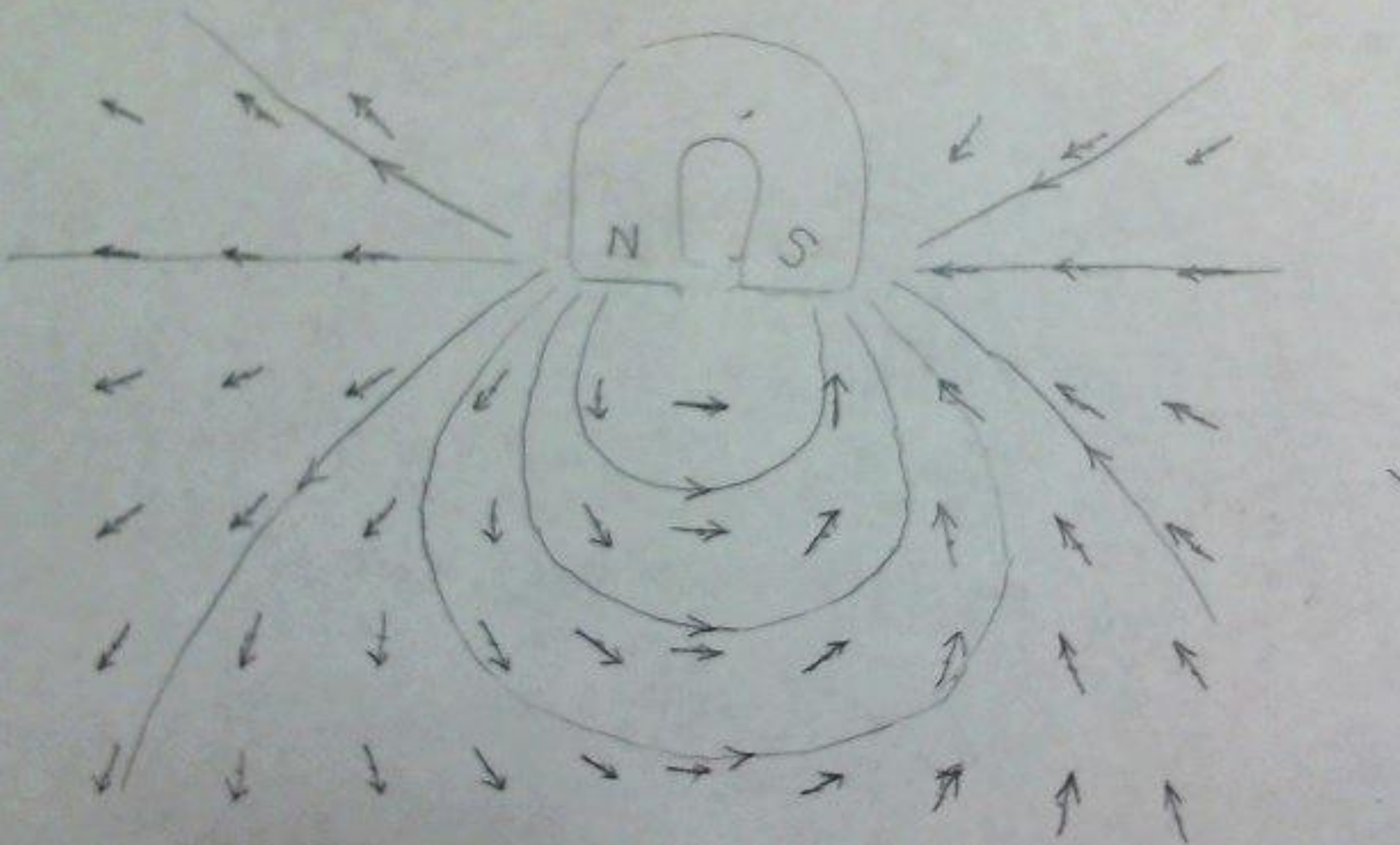
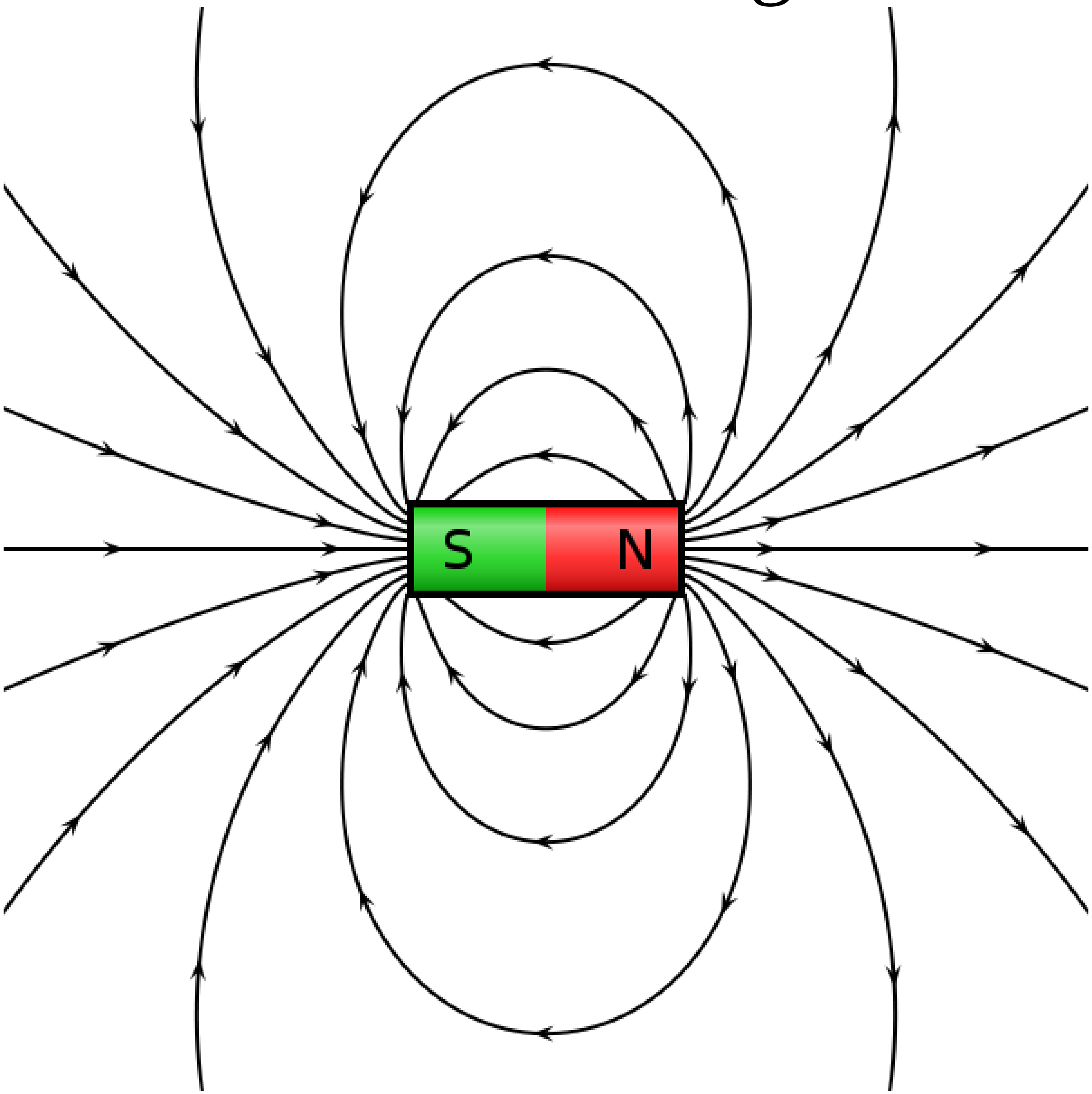


Field lines radiate outward from a magnetic north pole and converge on a magnetic south pole:



Field of Bar Magnet



Credit: Geek3, Wikipedia

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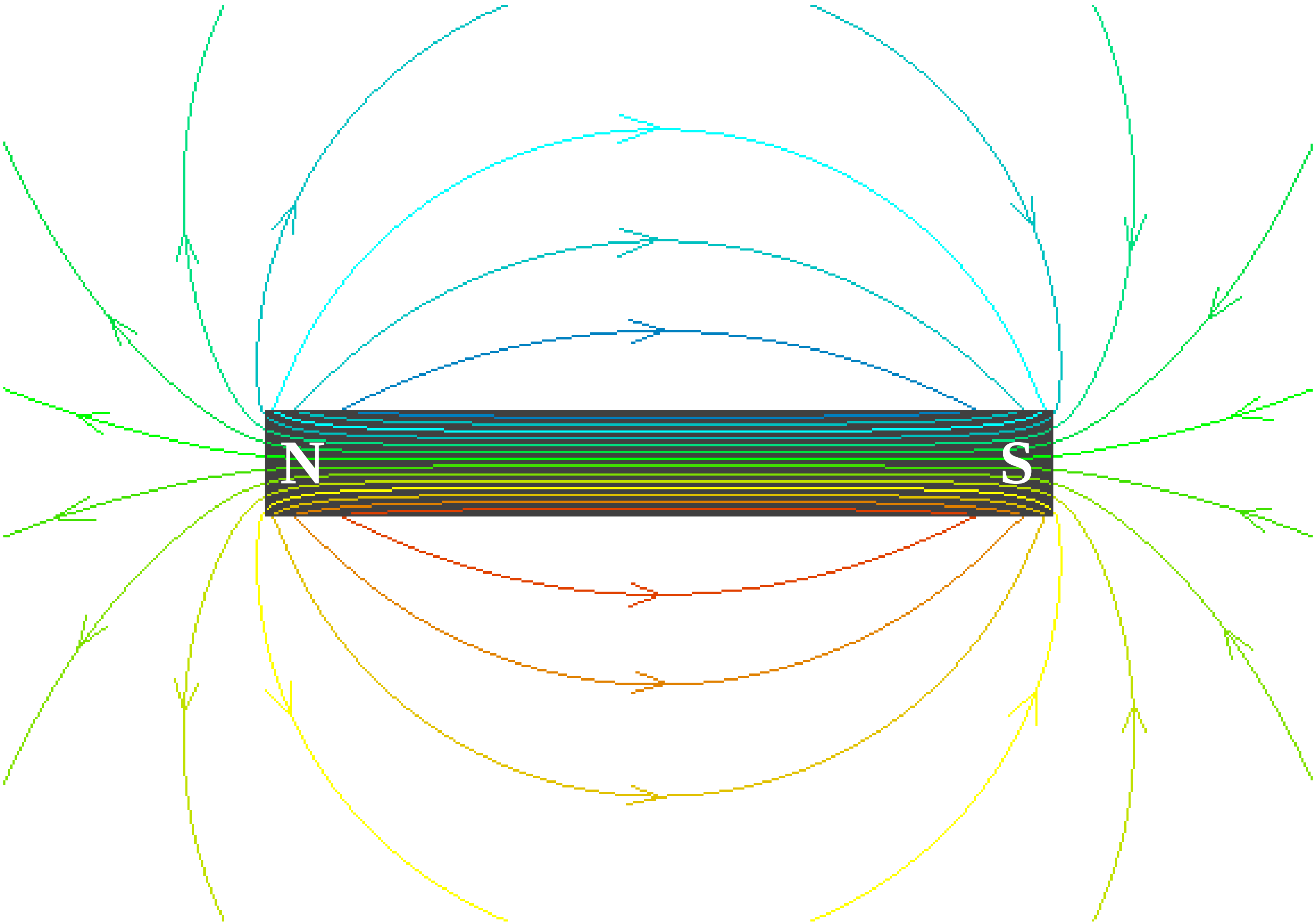
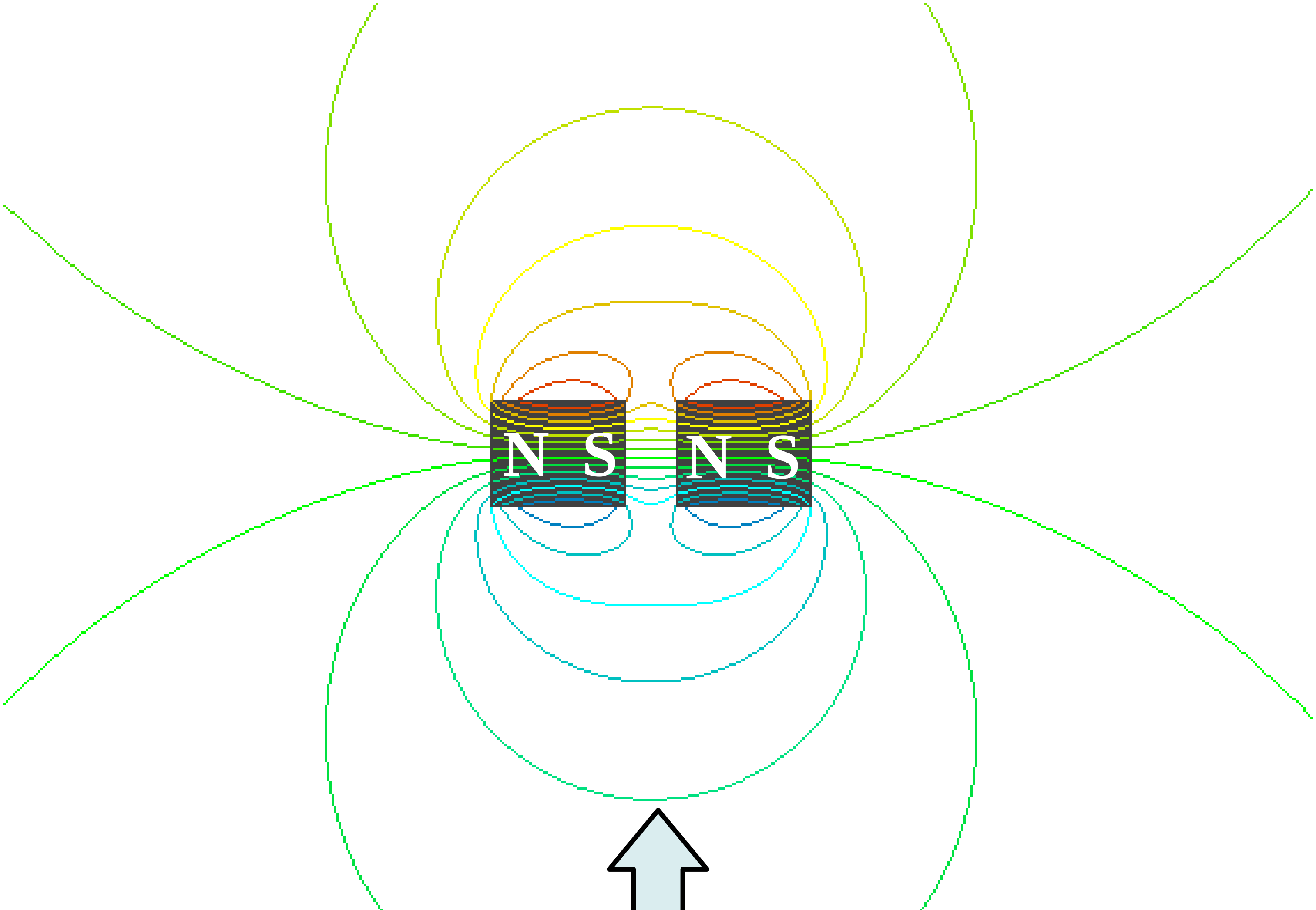


Superposition?

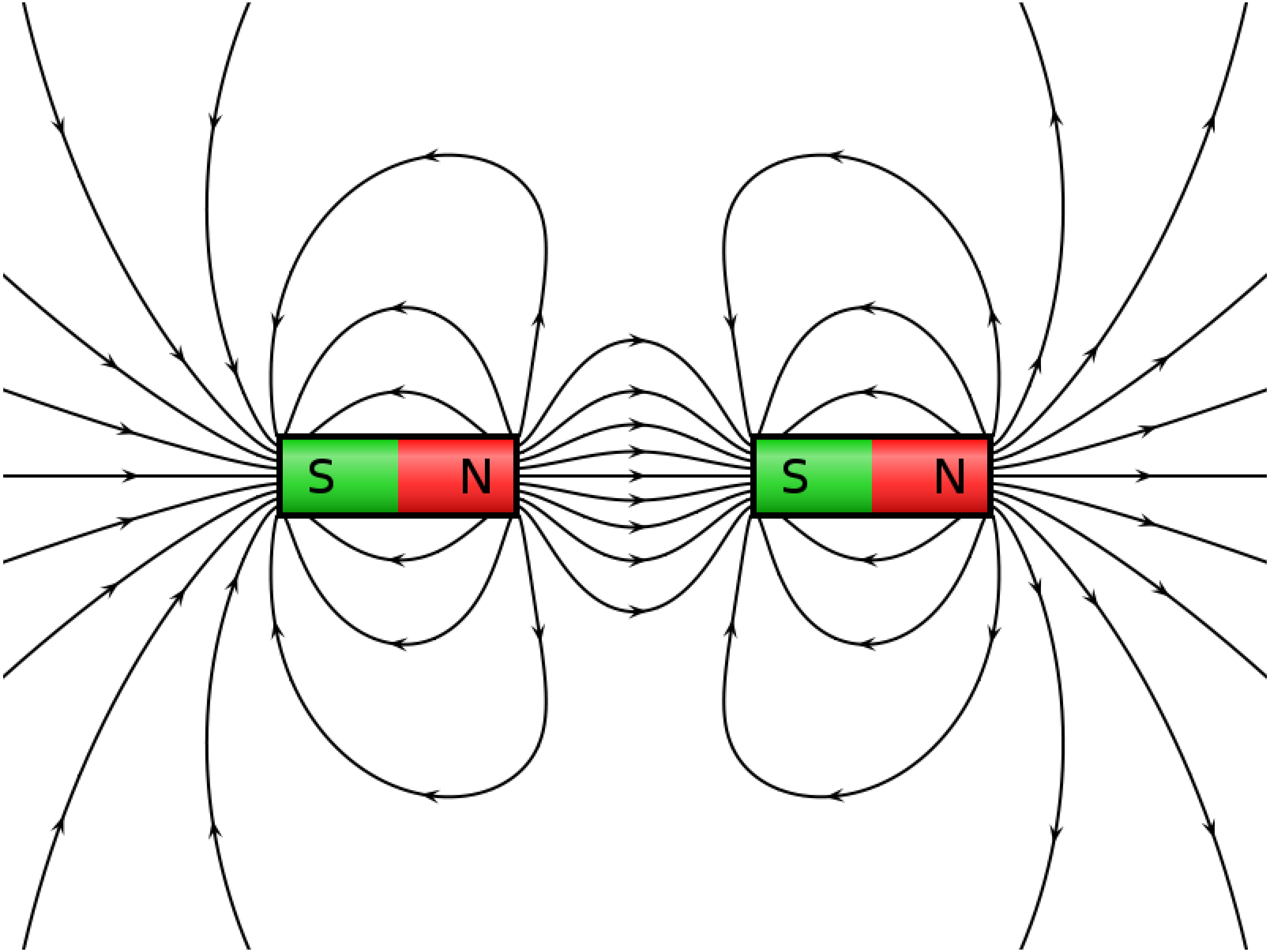
If magnetic fields follow the superposition priniciple:

1. How could two identical bar magnets be arranged to create a field twice as strong as either by itself? Sketch it!
2. How could two identical bar magnets be arranged so that one field cancels out the other? Sketch it!
3. Based on these ideas what would be a rule about fields that would predict the effect of one magnet on another: Magnets will attract when their fields…? Magnets will repel when their fields…? Interacting magnets will tend to move so that their two fields…?

Two Bar Magnets



Attraction occurs when *opposite* poles are in proximity. *But*, notice that the fields are aligned. Attraction occurs when the fields of each magnet are aligned in the *same* direction.



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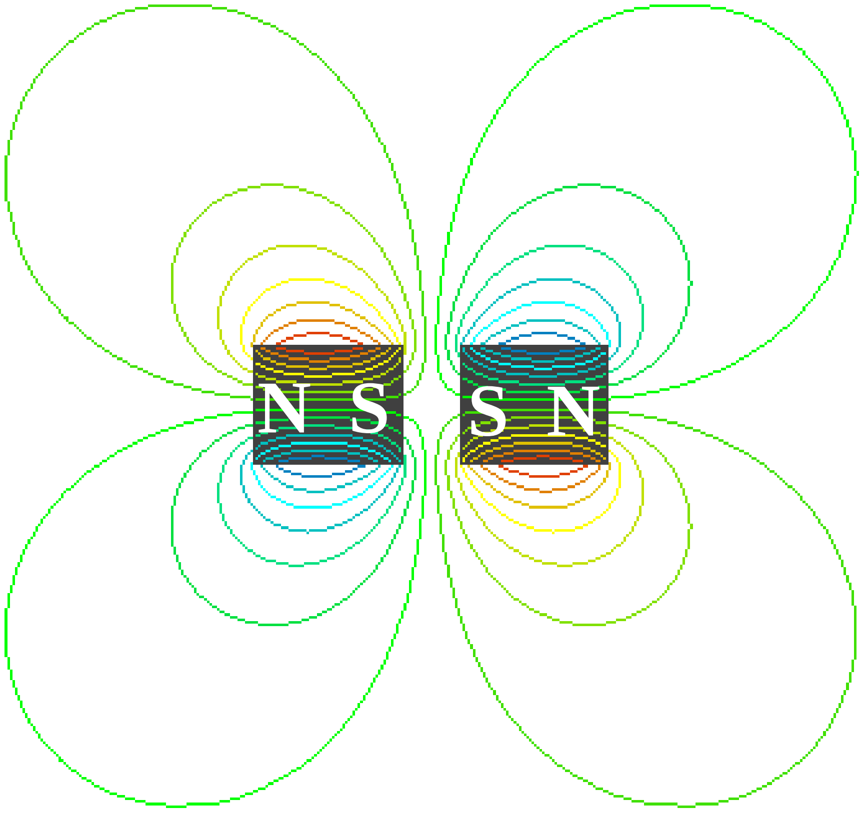
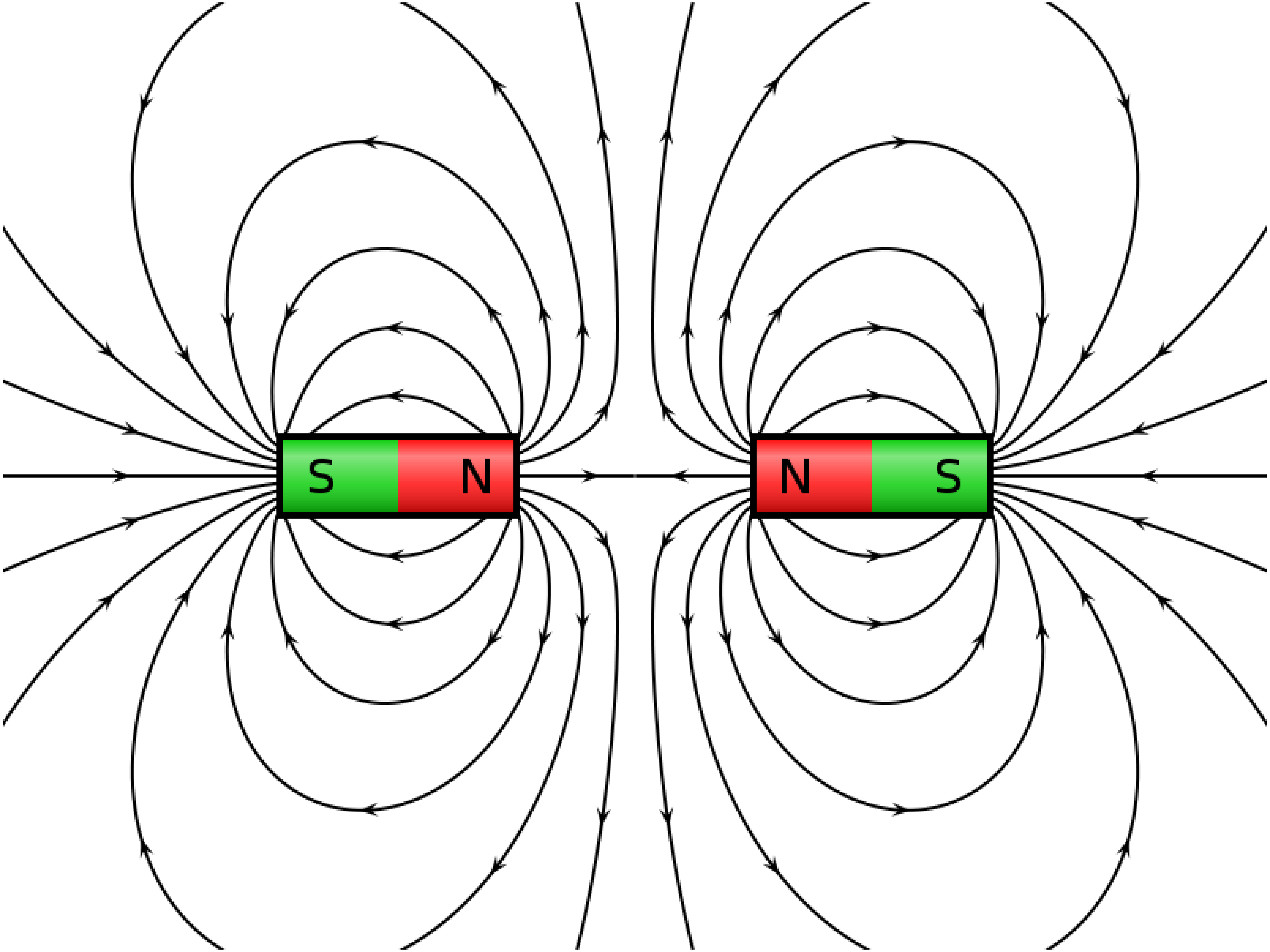
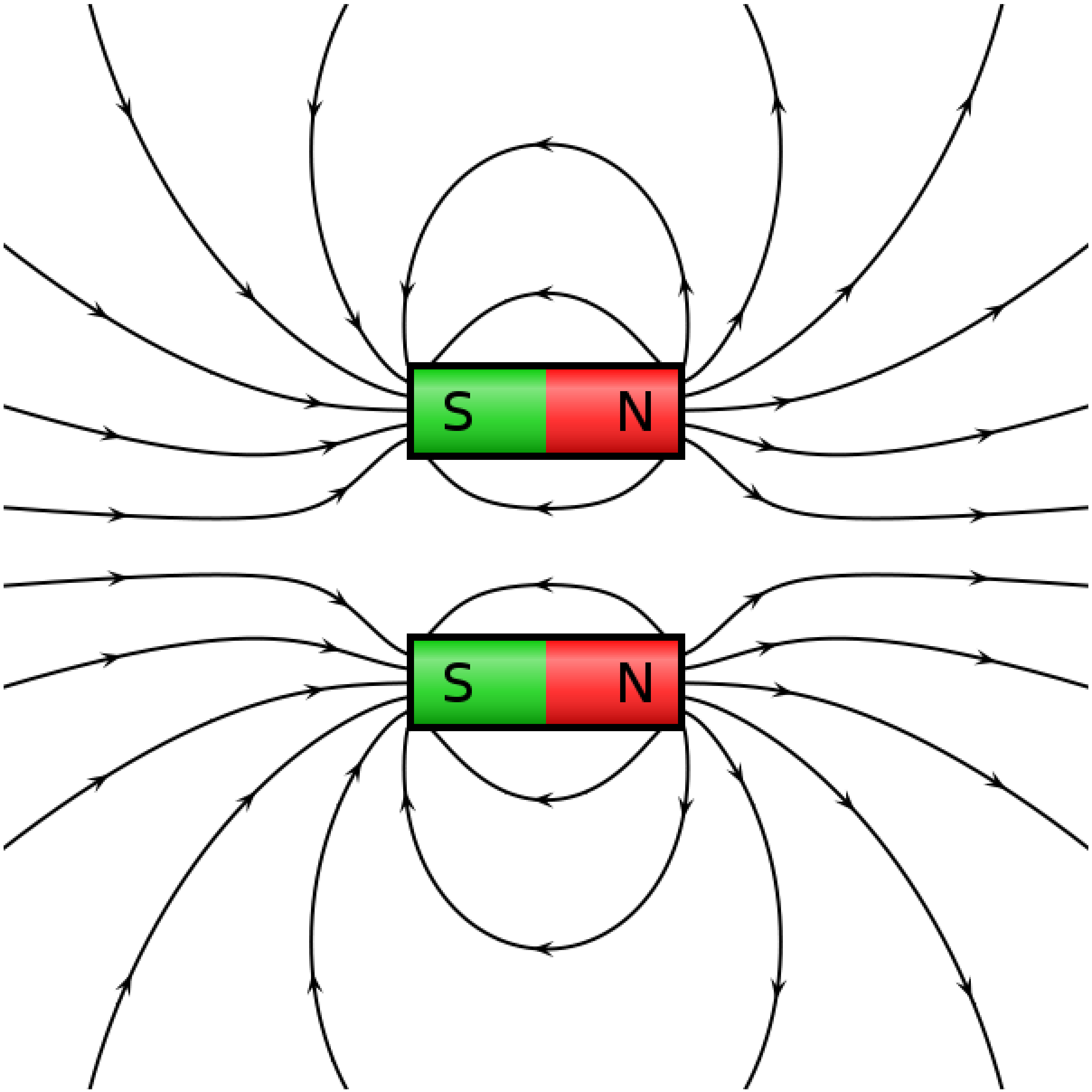


Repulsion occurs when *like* poles are in proximity. *But*, notice that the fields are opposed. Attraction occurs when the fields of each magnet are aligned in the *opposite* directions.



Credit: Geek3, Wikipedia



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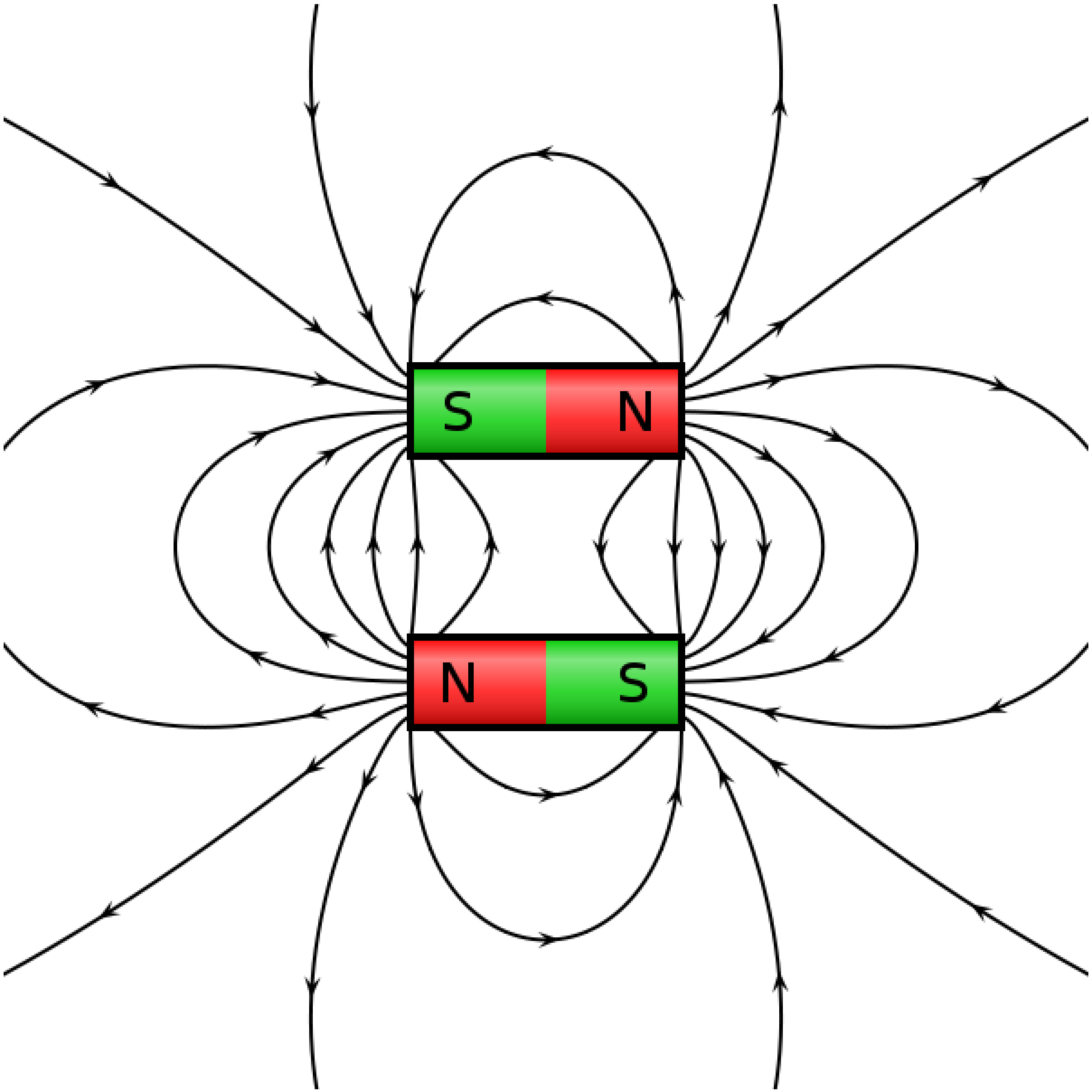

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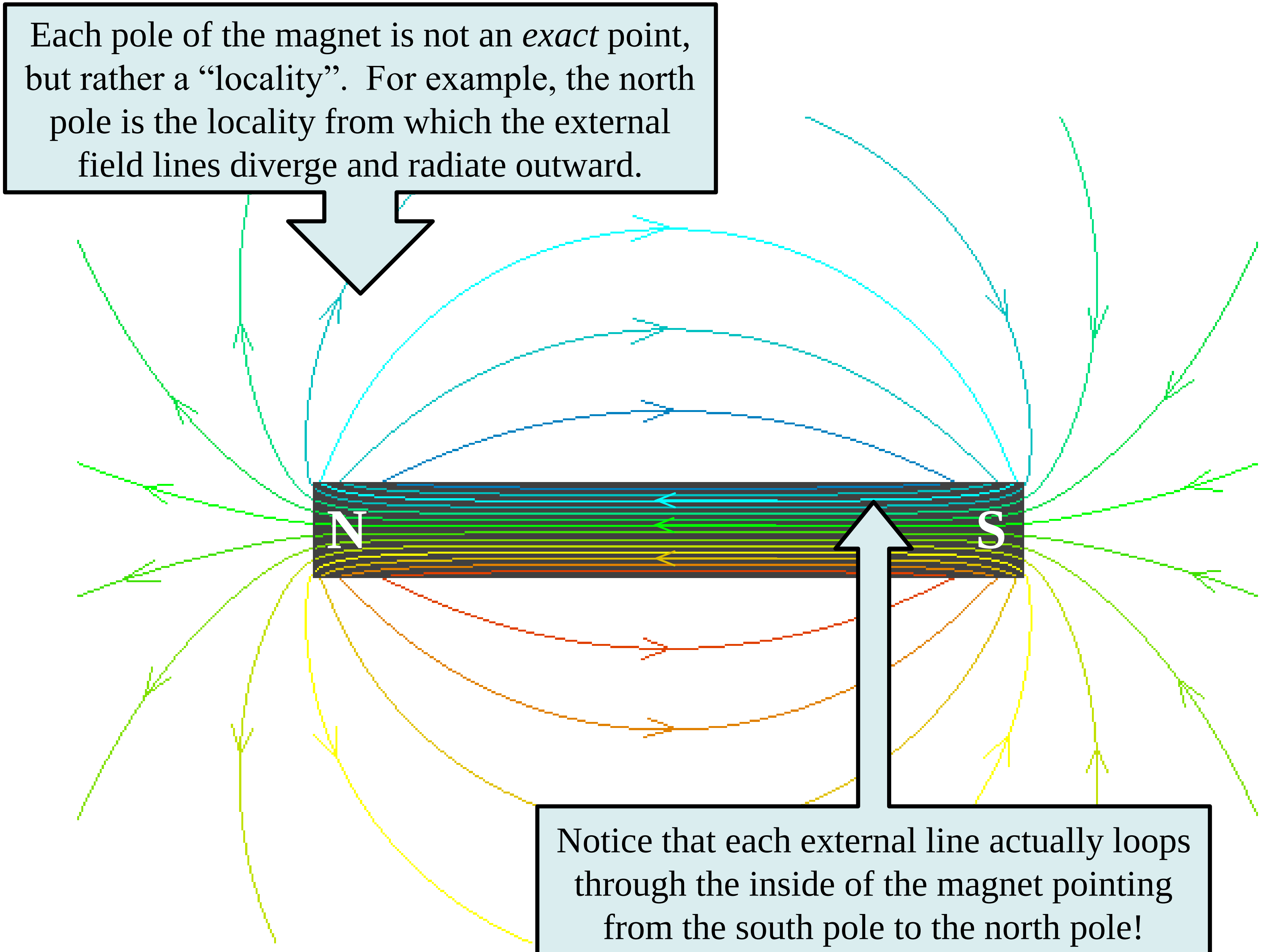
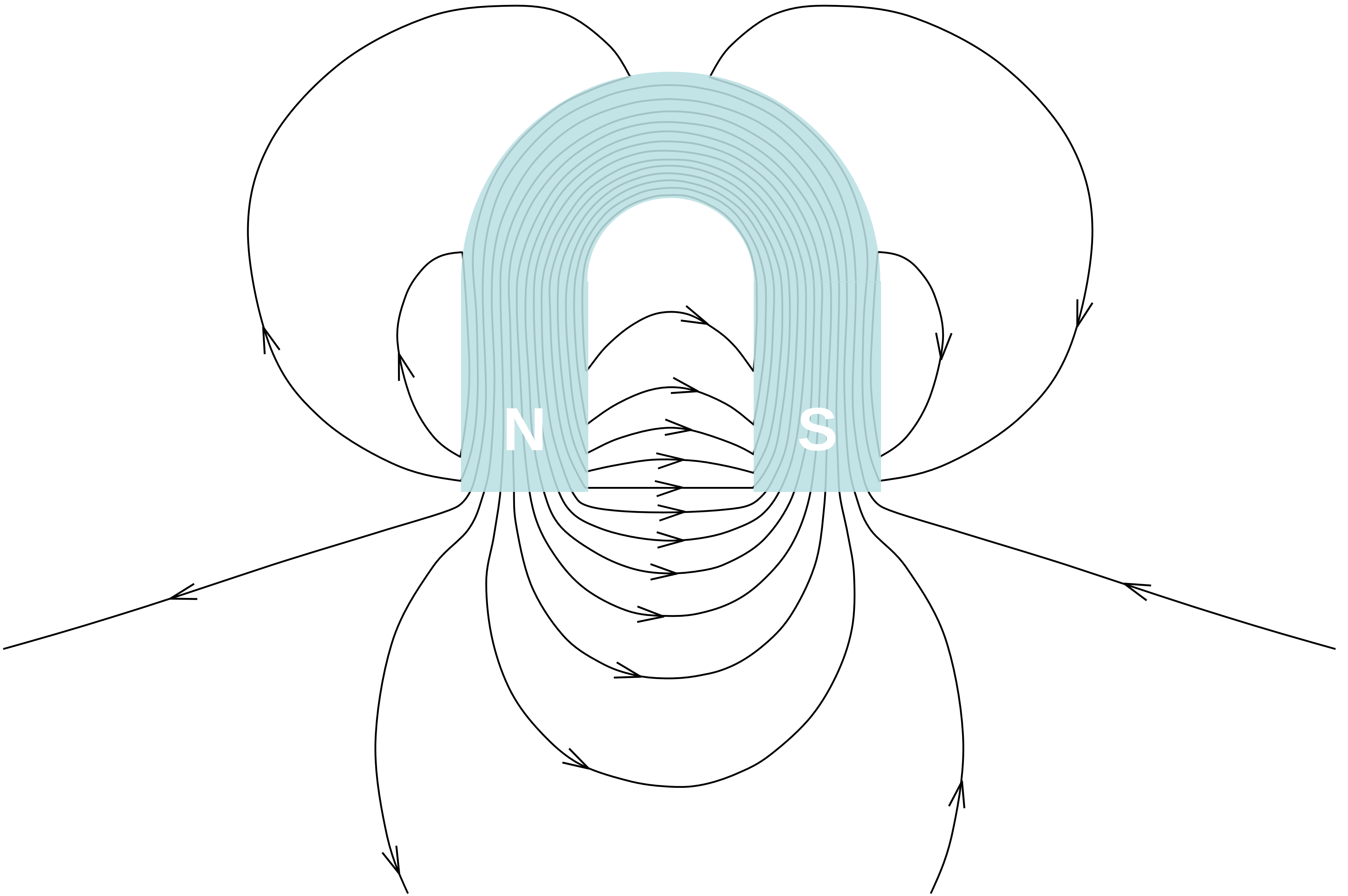
More on Poles and Fields

- It is not possible to isolate a magnetic pole.
- For example if a bar magnet is broken in half, each half will have a north and south pole.
- There is no “point source” for magnetic fields.
- An alternate way to describe interactions: magnets will tend to align so that overlapping fields point in the same direction.
- Magnetic field lines always form“continuous loops” of some shape.

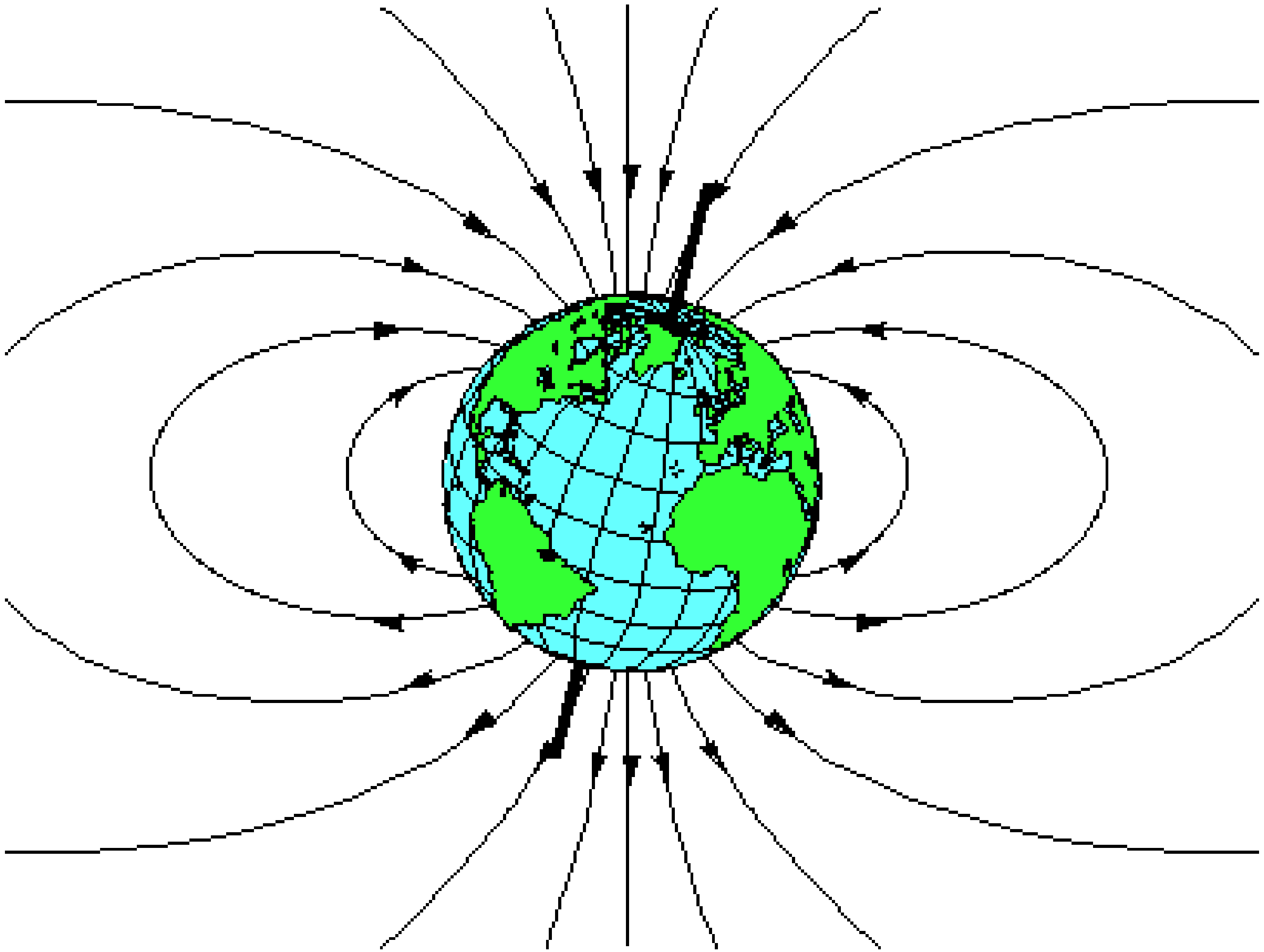
Field of Bar Magnet



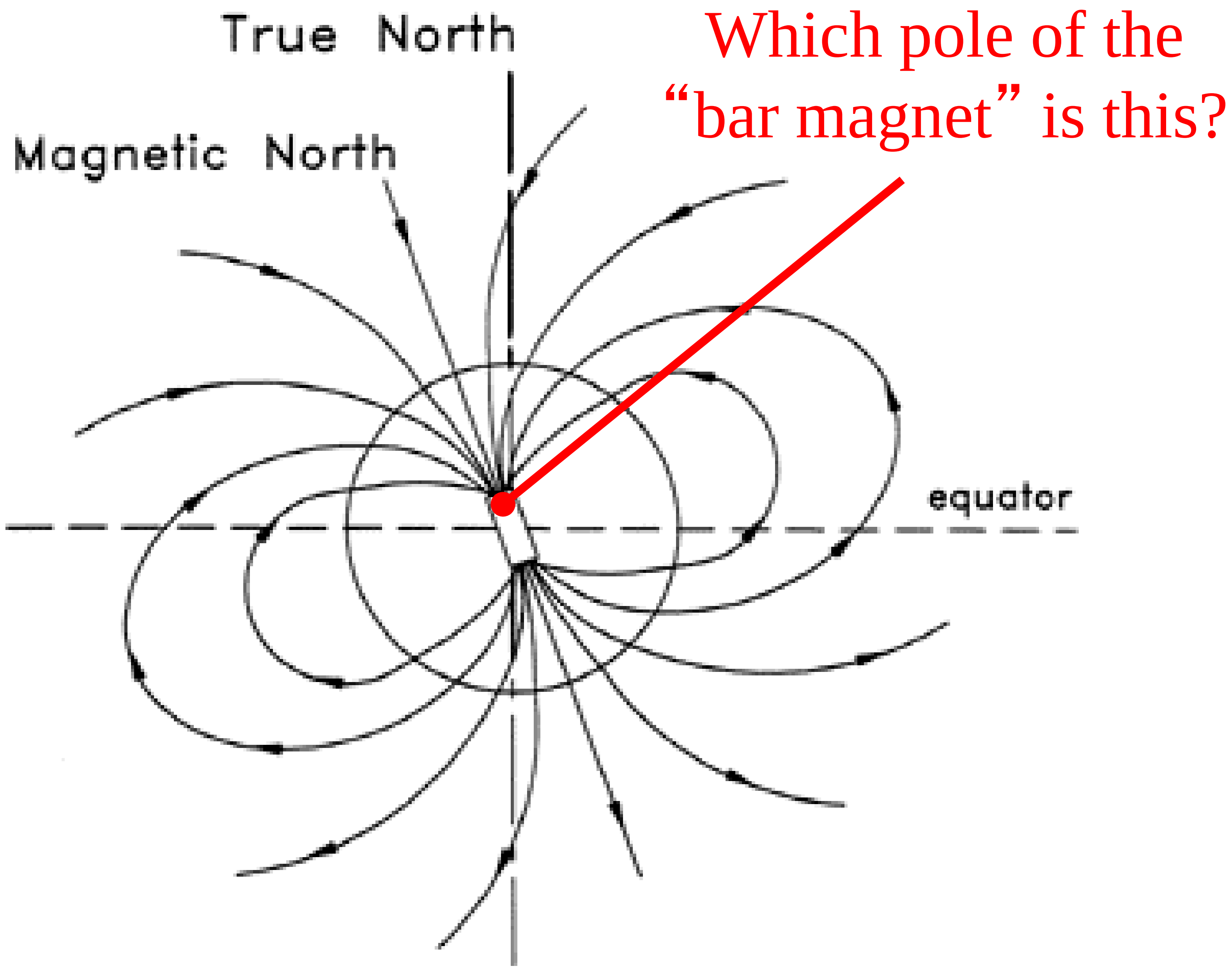
Field of Horseshoe Magnet



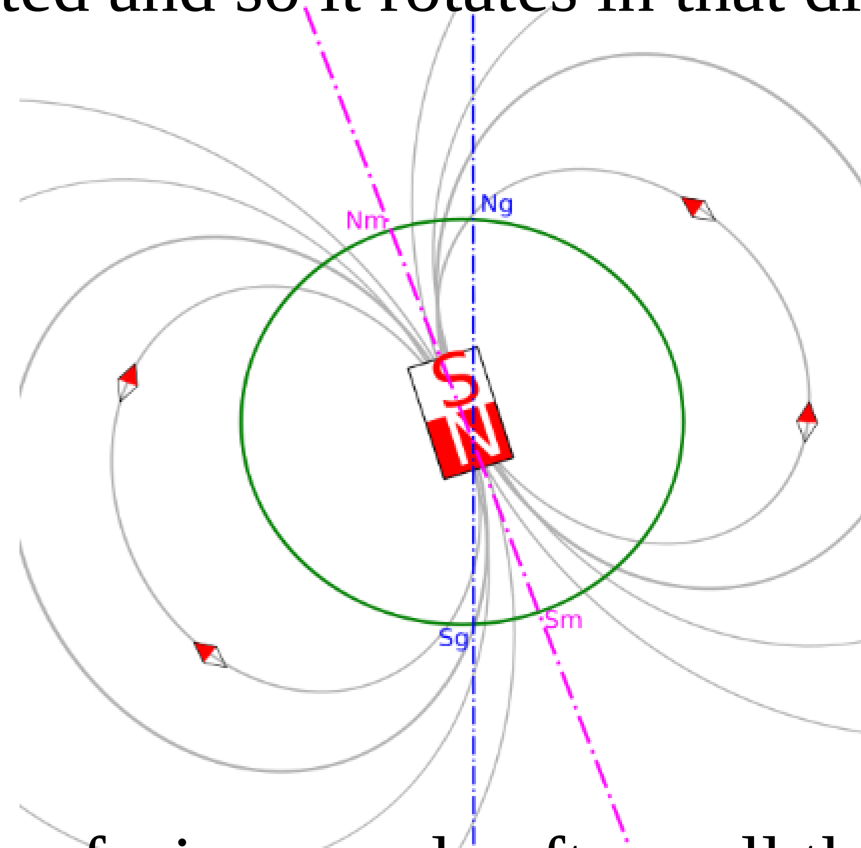
Earth's Magnetic Field



Externally it is very similar to that of a bar magnet.


True North
Magnetic North
equator
Which pole of the "bar magnet" is this?

The Earth's *geographic* north pole behaves like a *magnetic* south pole! The magnetic north pole of a compass needle is attracted and so it rotates in that direction.



To add to the confusion people often call the region towards which a compass points "magnetic north" to distinguish from the true north pole of Earth, which is defined by its axis of rotation, not its magnetic properties!