Today:

Finish a couple of slides Ch 23

Chapter 24: Magnetism

Final Exam

Tue Dec 20, 11.30am—1.30pm

- Cumulative, multiple-choice, 2-3 qns per chapter up to Ch 22, and 5-6 qns per chapter after that.
- All questions you will have seen before on lecture slides, midterms, or review sessions (inc. final review session)

Note: Teacher Evaluation Period has begun: please log in using Hunter netID and pwd:
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Magnetism

Magnetic Forces

- What is the origin of the magnetic force? **Moving charged particles** (more later). E.g. Orbiting electrons in the atoms making up a magnet.

- Stationary charged particle – produces electric field
- Moving charged particle – produces both an electric field and a magnetic field.

- Actually, electrical and magnetic forces are intimately related through relativistic considerations – different manifestations of "electromagnetism".

Magnetic Poles

- Magnetic poles – from which magnetic forces emanate.
- Two types: north and south

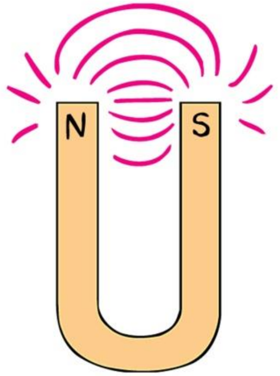
Eg. Bar magnet

- *Every* magnet has *both* a north and a south pole
- Like poles repel each other; unlike poles attract.
- Simple compass:

Suspend bar magnet from its center by a piece of string. Convention is that the north pole points northward; south pole points southward.

- This means that the Earth’s “north pole” is actually a magnetic south pole! And vice-versa.

Magnetic Poles cont.



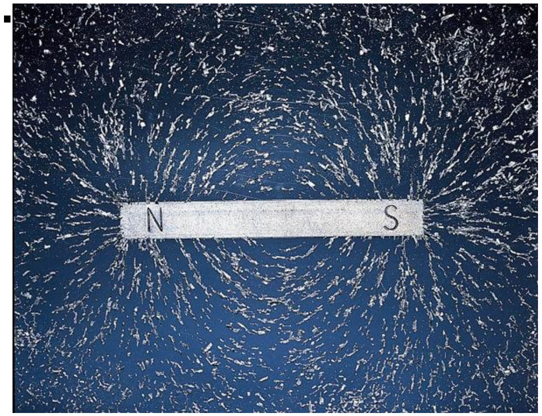
- Another type: Horseshoe magnet

- Fridge magnets – have narrow alternating N and S strips. Strong field near the magnet but field decays quickly with distance since N and S fields cancel.

- Magnetic poles cannot be isolated. (Big difference with electric charge) e.g. if break bar magnet in two, each half behaves as complete magnet, each with N and S poles. Even when it’s one atom thick! *No magnetic monopoles*.

Magnetic Fields

- Iron filings sprinkled around bar magnet align with the magnetic field.

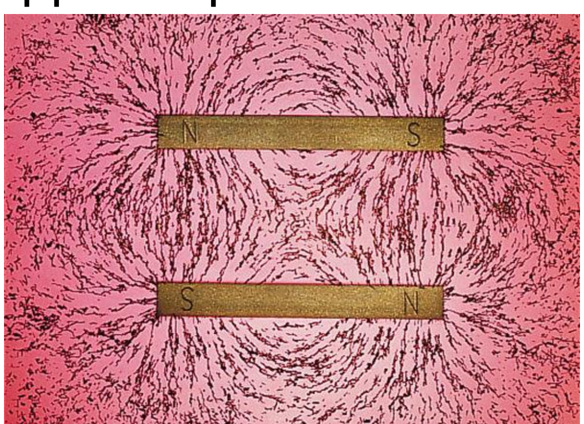


(c.f. electric field lines earlier)

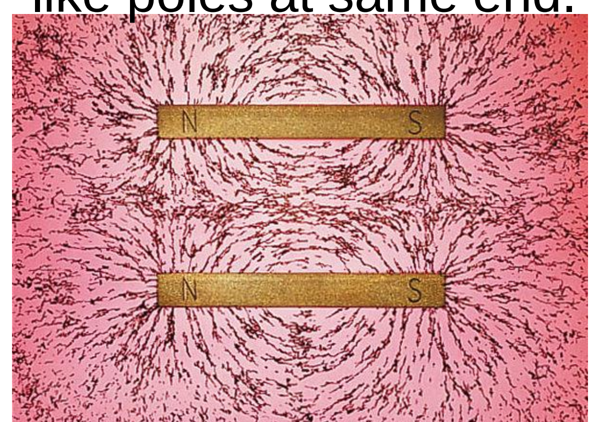
Field is stronger where lines are more dense

Actually magnetic field lines form closed loops – they continue inside the magnet (not shown in pic)

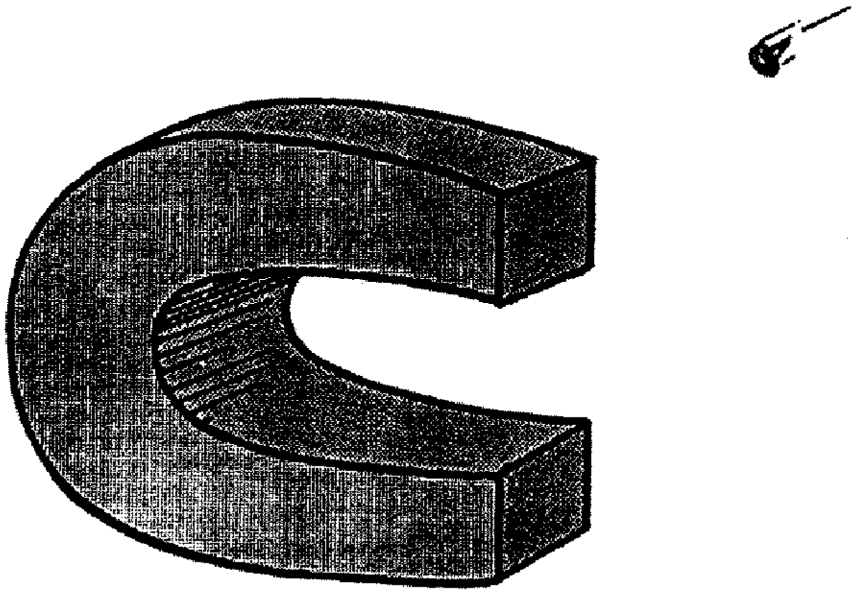
Eg. Two bar magnets with opposite poles at same end



Eg. Two bar magnets with like poles at same end.

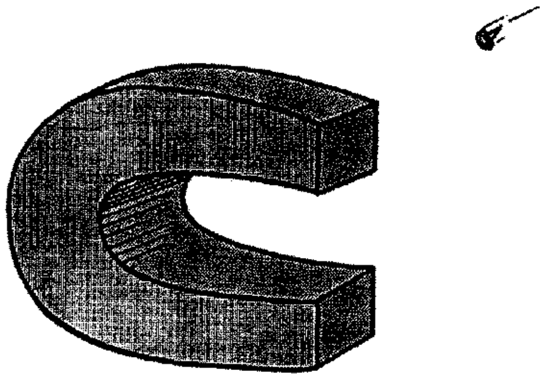


Clicker Question



Compared to the huge force that attracts an iron tack to a strong magnet, the force that the tack exerts on the magnet is

1. relatively small.
2. equally huge.



Compared to the huge force that attracts an iron tack to a strong magnet, the force that the tack exerts on the magnet is

1. relatively small.
2. **equally huge.** ✔

Answer: 2

The pair of forces between the tack and magnet comprises a single interaction and both are equal in magnitude and opposite in direction—Newton's third law. Because of its much larger mass, the resulting motion of the magnet is negligible compared to the motion of the tack.

What motion makes a stationary bar magnet magnetic?

- The moving charges are the electrons – undergoing two kinds of constant motion:

  (i) spin, like "tops" *(although, really need quantum mechanics to describe this)*

  (ii) orbit (revolve) about nucleus

Usually spin is the significant contribution

- Every spinning electron is a tiny magnet. Net magnetism comes from sum of fields from every electron.

- Non-magnetic materials: consists of pairs of electrons spinning in *opposite* directions, so their fields cancel each other, and there is no net magnetic field.

- Magnetic materials: eg iron, nickel, cobalt, not all spins are cancelled out. Eg. each iron atom has 4 electrons whose spin magnetism isn't cancelled.

Magnetic Domains and Making Magnets

- Magnetic field of an individual iron atom is so strong, that it makes neighboring atoms line up - get clusters of billions of aligned atoms, called **magnetic domains**.
- Also, domains themselves can align with each other.
- But the domains are generally in independent, random orientations – so a common piece of iron is *not* a magnet.
- Only when they align with each other, does the piece of iron become a magnet.

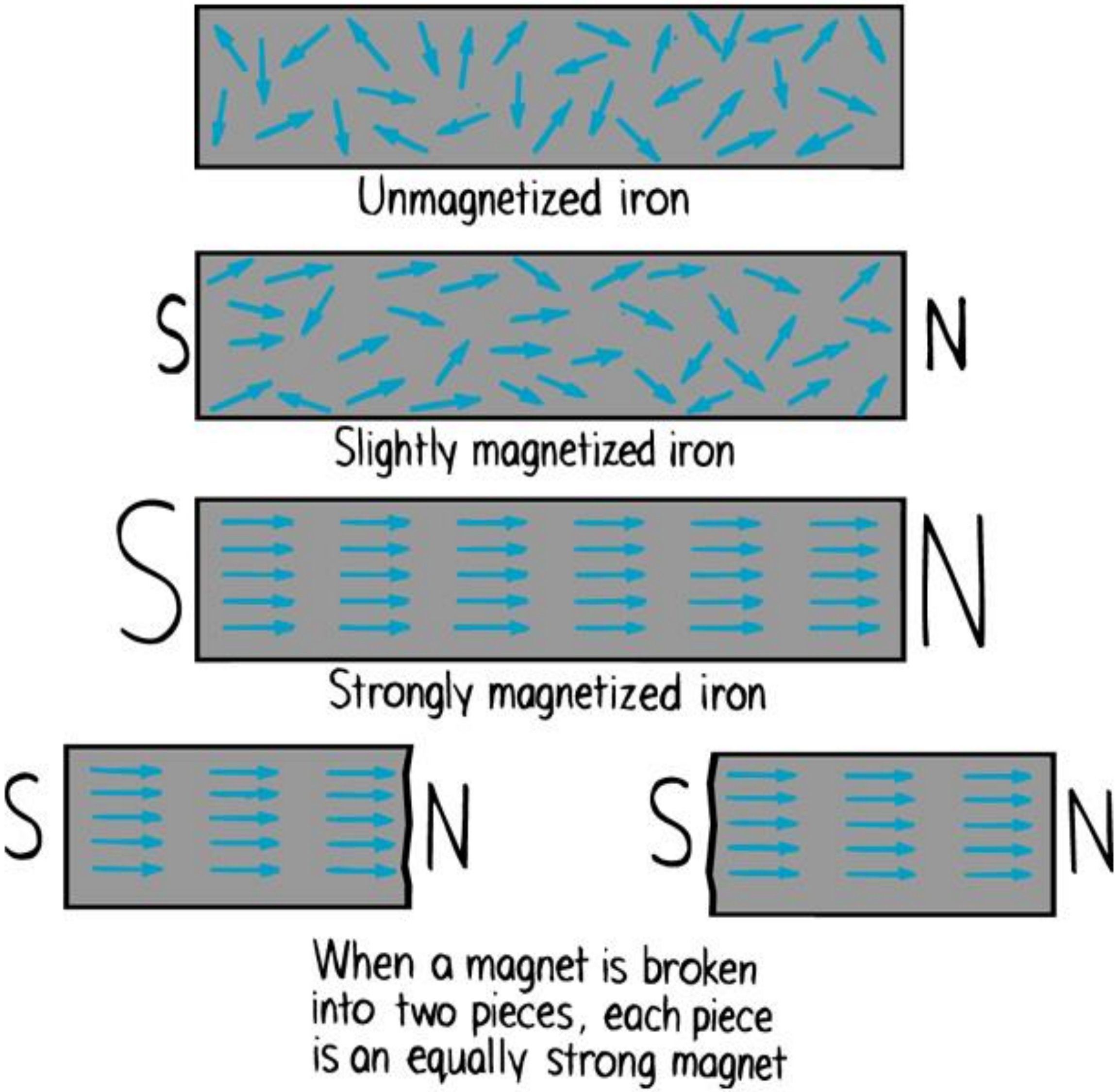
This is how permanent magnets can be made! Tapping the iron helps align any stubborn domain

• Can make them align by bringing a (permanent) magnet nearby – if this magnet is strong enough, then when you separate them again, the iron piece may retain the alignment, and so be magnetic.

• But if not strong enough, then on removing the permanent magnet, the domains in the iron piece thermally move back to a random arrangement.

• Another way to make magnet: stroke iron piece with magnet – aligns domains.

Here are the stages in magnetizing a piece of iron:



Clicker Question

If a magnet is dropped or heated, does the magnetism get weaker, and why?

A) No, in fact it increases since the electrons move faster.

B) Yes, because domains get jostled out of alignment.

C) No, it doesn't change

D) Yes, because some of the electrons leave the magnet.

Answer: B

Question: Place an unmagnetized piece of iron in a magnetic field (eg iron filings near a magnet). Why is it attracted to the magnet?

Because the field brings domains of the iron piece into alignment. So the iron piece develops a N and S pole. The induced N is then attracted to the permanent magnet's S, etc.

(c.f. concept of polarization in electric case)

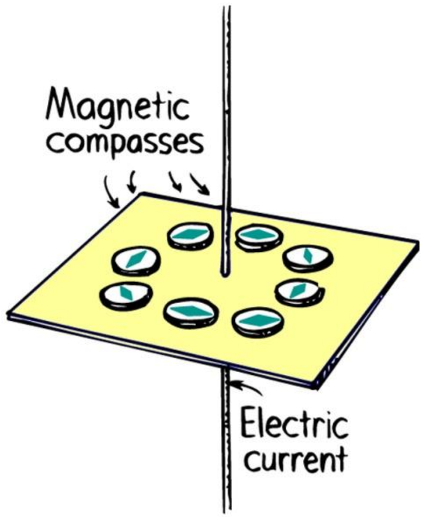
In fact, most iron-containing objects around you are magnetized to some extent – largely induced by Earth's magnetic field.

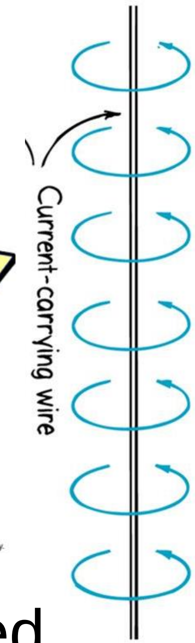
Electric currents and magnetic fields

- Current = moving charges, so current produces magnetic field.

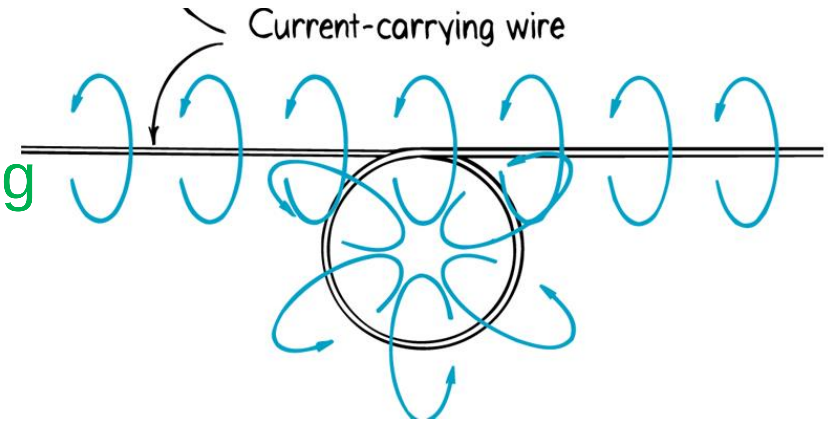
Eg: put compasses around current-carrying wire: needles align circularly – Magnetic field lines form circ. loops around wire.

If reverse direction of current, all needles reverse direction

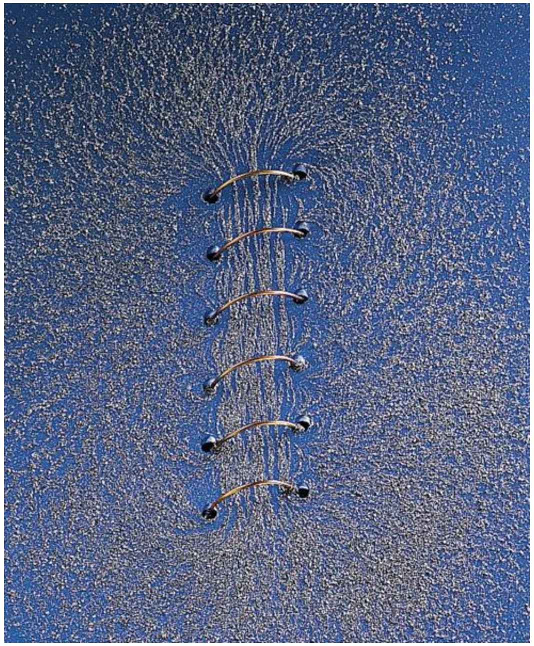




- If bend wire around into a loop, field loops get bunched in the middle, all pointing in the same direction there:



- **Electromagnet** = current-carrying coil of wire.



Electromagnets cont.

- Can increase strength of field by

  - increasing current

  - using several overlapping coils (intensity grows as # of coils)

  - putting an iron core within the coil (mag domains of iron induced into alignment and so add to the field)

- Eg. Used to lift cars in junkyards.

Limiting factors – heating from large currents (due to electrical resistance)

-- saturation of domains (i.e. all aligned) in iron core

- Most powerful use superconductors (and no iron core) since can conduct large currents (almost zero resistance)…maglev…

Clicker Question

The field surrounding every moving electron is

A) always magnetic but never electric.
B) always electric but never magnetic.
C) sometimes magnetic and sometimes electric.
D) always both electric and magnetic.
E) none of the above

Answer: D
Even a stationary electron produces an electric field, but if it is moving then both an electric and magnetic field are generated.

Magnetic force on moving charged particles

- When a charge is *moving*, it experiences a force if in a magnetic field.

- Strength of force depends on

  - **strength of field**

  - **charge's velocity** (faster→ stronger. *No* force if stationary!)

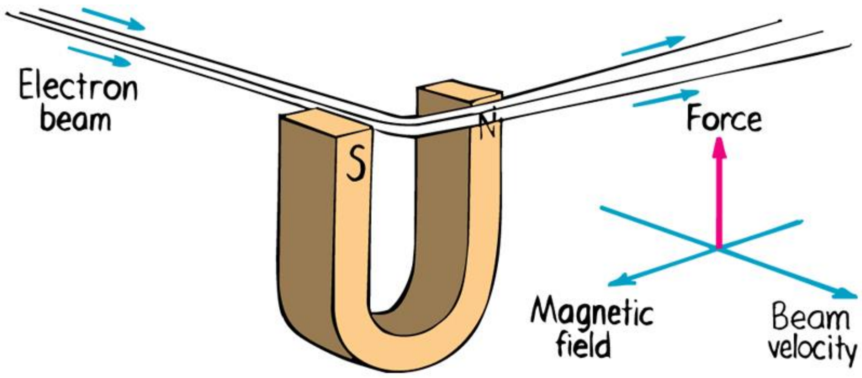
  - **size of charge** (larger →stronger. *No* force if uncharged!)

  - **relative direction** of charge's velocity to the field - **strongest if moving perpendicular to field.** Note, *no* force if its moving parallel to the field!

- **Direction of force is perpendicular to both the magnetic field, and to the particle's velocity.**

Magnetic force on moving charged particles cont.

Eg:
Electron beam is deflected upwards.



Notes:

If protons instead, force downwards.

If electrons, but moving in opposite dir, force downwards.

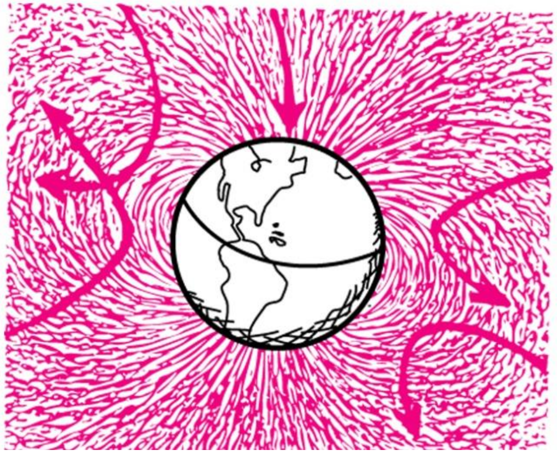
Magnetic force on moving charges cont.

- Note big difference with grav force and electrical force:

  - magnetic force does not act along the line joining the interacting objects; rather it is *perpendicular* to both field and the charge's path.

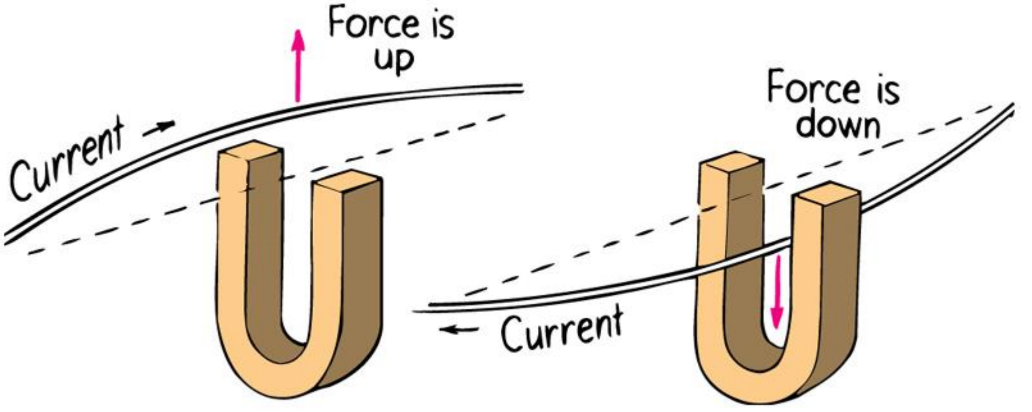
- This deflective action is used in (old style) TV's

- Cosmic rays: charged particles streaming in from the sun fortunately get deflected by the earth's magnetic field lines (see more later)



Magnetic force on current-carrying wires

- Current = moving charges, so current also experiences deflection in a magnetic field; wire gets pushed perpendicular to field:



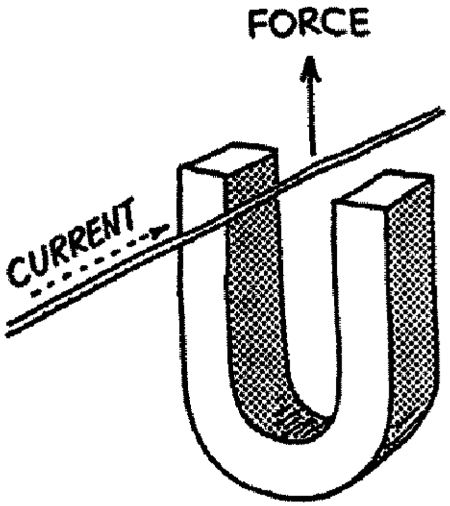
Deflection direction is reversed when current direction is.

- Note complementary property (related to 3rd law):

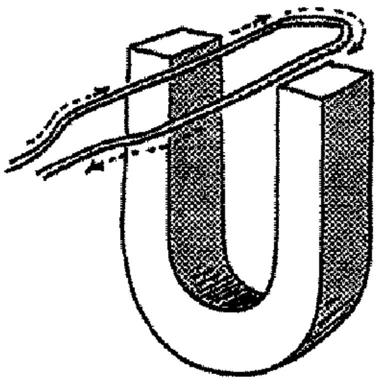
Recall a current-carrying wire has an associated magnetic field, so deflects a magnet.

Likewise, here a magnet deflects a current-carrying wire.

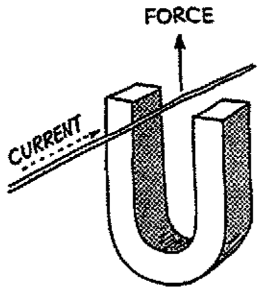
Clicker Question



When the current flows in the wire that is placed in the magnetic field as shown, the wire is forced upward. If the wire is made to form a loop as shown, the loop will tend to



1. rotate clockwise.
2. rotate counterclockwise.
3. remain at rest.



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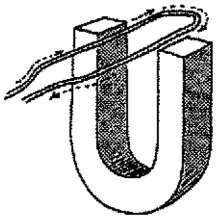
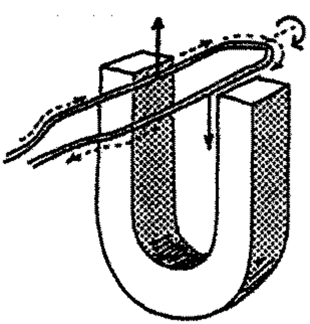
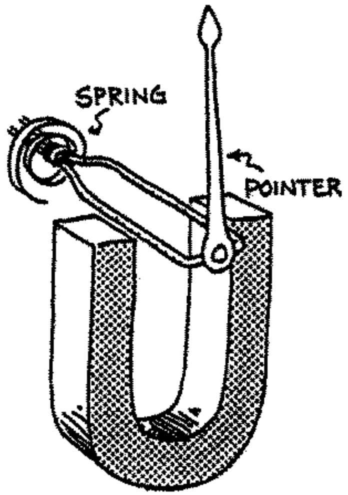


1. **rotate clockwise.**
2. rotate counterclockwise.
3. remain at rest.



Answer: 1

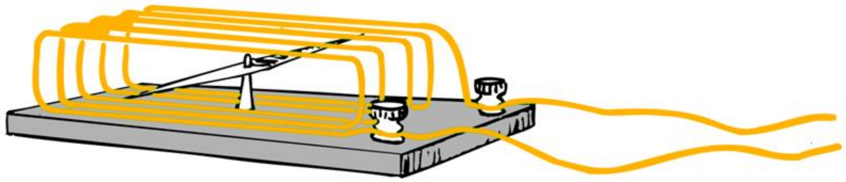
The left side is forced up while the right side is forced down as shown. You can make a simple electric motor with this if you make the current change direction (alternate) at every half turn, it will rotate continuously as long as the alternating current persists. Then you have a motor –see lecture.



Electric Meters

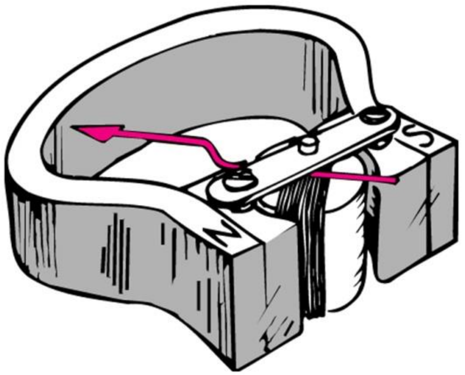
i.e. a current-detecting device.

- Simplest: a magnet that is free to turn (ie a compass)
- Next simplest: a compass in a coil of wires, so that magnetic field sensed by compass is increased:



So can detect very small currents – called *galvanometer*

- More common design for galvanometer -



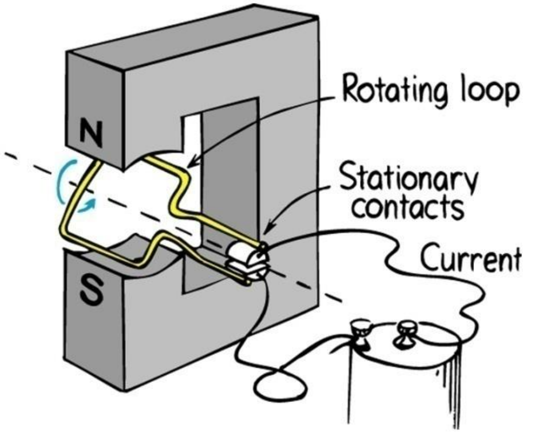
Magnet held stationary. Many loops of wire, so more sensitive; rotates when current is flowing, and deflects a spring.

Can be calibrated to measure current (*ammeter*), or voltage (*voltmeter*).

Electric motors

- Designed so that deflection makes a *complete* rotation (instead of partial, as in a galvanometer)
- How ? Consider simplified motor:

Current on one side of the loop flows in the opposite direction to the current on the other side of loop. So, the two sides gets deflected in opposite directions, as shown; hence it turns.



After a half turn, the sides have reversed, so deflection is in the opposite direction – makes coil turns back.

• To prevent this, *reverse the direction of current every time coil makes a half rotation.*

• Then rotation is continuous, in one direction.

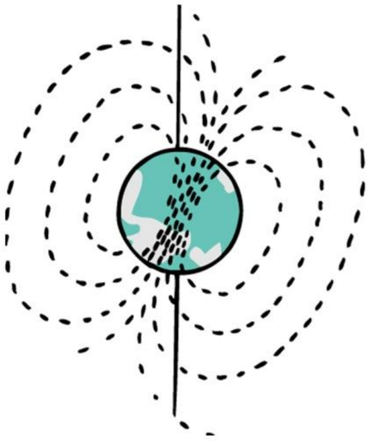
• In most motors today, replace the magnet with an electromagnet, fed by the power source.

Earth's magnetic field

- Magnetic poles of Earth are actually about 1800 km from the geographic poles.

  So compasses do not generally point to the true (i.e. geographical) north and true south.

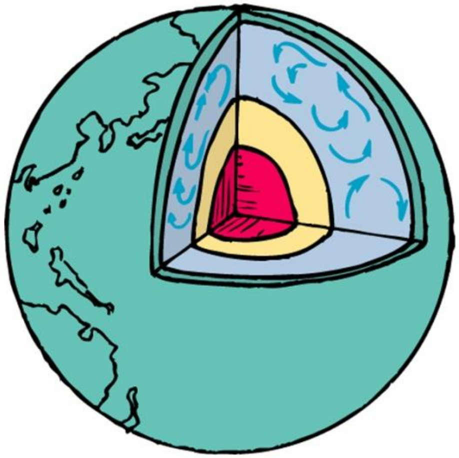
  Effect is called *magnetic declination*.



- What gives Earth its bar-magnet -like property?

Somewhat unresolved problem.

Atoms too hot to maintain fixed orientation. Instead, thought that in the molten part of earth, surrounding solid core, moving charges loop around, creating the earth's magnetic field. But what causes the currents? Also not completely understood. Maybe thermal energy from core giving convection currents.



More on Earth's magnetic field

- Unstable – it can diminish to zero, and then reverse direction. More than 20 such pole reversals have occurred in the past 5 million years! Next one expected within 2000 years.

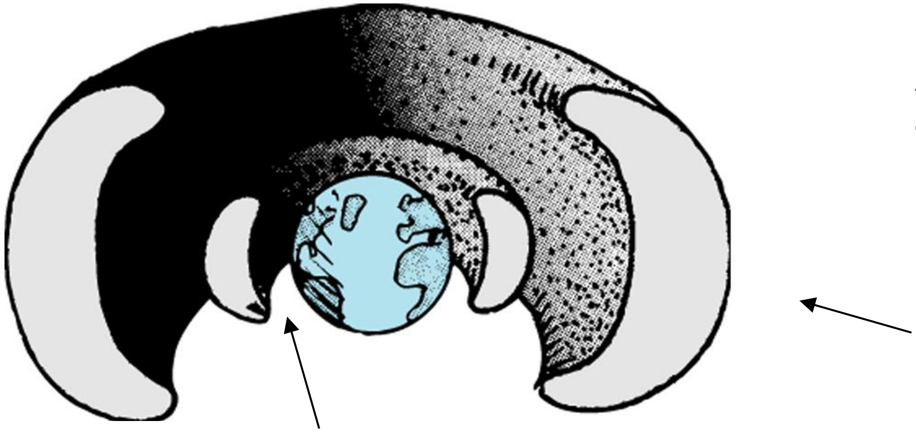
  Can detect from magnetization within Earth's upper rock strata…see book for more on this…

- Sun's magnetic field also reverses regularly, every 22 years.

- Smaller and faster fluctuations in Earth's field are from varying ion winds in atmosphere. Ions created from solar ultraviolet and x-rays interacting with atmospheric atoms.

Cosmic rays

- Are actually **charged particles** (protons, or other atomic nuclei), produced by sun, or other stars.
- Travel at speeds close to the speed of light
- Dangerous radiation for humans; also can mess up electronic instrumentation.
- Earth's magnetic field protects us from them by deflecting them back (previous picture, also next slide)
- Some are trapped, spiralling back and forth along field lines, in two "van Allen radiation belts":



Astronauts orbit well below the inner one.

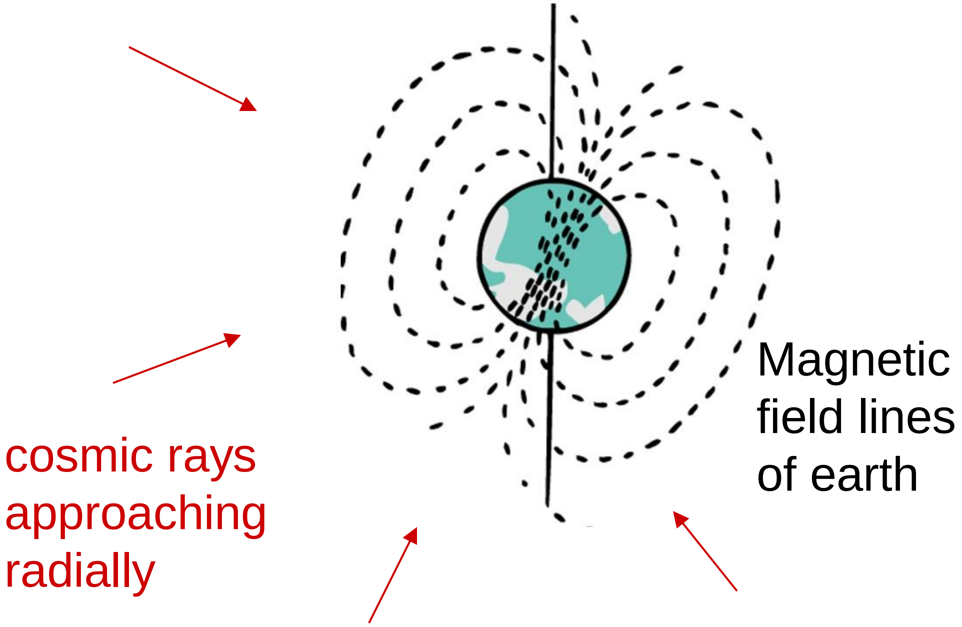
Outer ring ~ 16 000 km over head. Mostly electrons, also protons; largely from sun.

Inner ring ~ 3200 km overhead. Mostly protons. Probably originated from earth.

Clicker Question

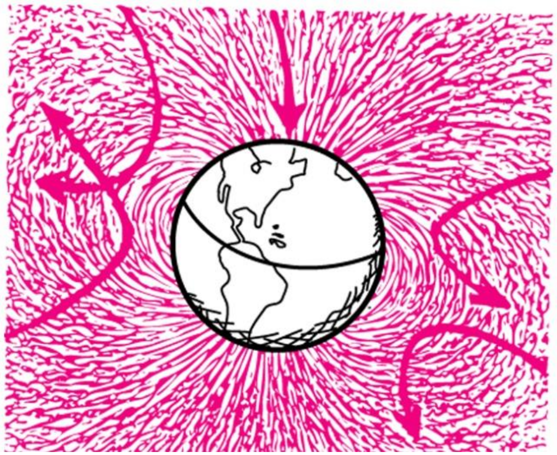
The intensity of cosmic rays bombarding the Earth's surface is largest at the

A) mid-latitudes.
B) equator.
C) poles.



Answer: C

The magnetic field lines of the Earth deflect incoming charged particles of the cosmic ray, when they enter at right-angles to the field lines. At the poles, the rays come in more parallel to the field lines than at the equator, so there is less deflection



When ions dip into Earth’s atmosphere, get beautiful light shows from fluorescence: *aurora borealis* (northern hemisphere), and *aurora australis* (southern hemisphere)

- Spaceflights try to avoid the belts, since hazardous to astronauts and instruments.

- Although Earth’s field protects us on earth’s surface from “primary” cosmic rays, we do get bombarded with “secondary” ones – when primary rays strike atomic nuclei high in atmosphere.

- Greatest bombardment at the magnetic poles, because the rays come in parallel to the field lines so don’t get deflected as much as those coming in near equator, perpendicular to field. Mid-latitudes, about 5 particles per square cm at sea-level!

Biomagnetism

- Some animals have magnetite (iron oxide) domains in their bodies i.e. a built-in compass, allowing them to sense magnetic fields, and thus navigate!

Eg. Some bacteria, pigeons, wasps, monarch butterflies, sea turtles, bees…

- Read book for more on this.

Clicker Question

An electron is shot through a spot somewhere between the ends of a horseshoe magnet. The electron

A) is unaffected by the field.
B) is attracted to one of the poles, and repelled by the other.
C) is repelled by both poles, and therefore is turned back.
D) speed is increased.
E) direction is changed.

Answer: E
Magnetic fields deflect moving charges – i.e. the magnetic force is in a direction perpendicular to both the charge's velocity and the magnetic field.