

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

V. Magnetism in Matter

Permanent magnets

Domain theory

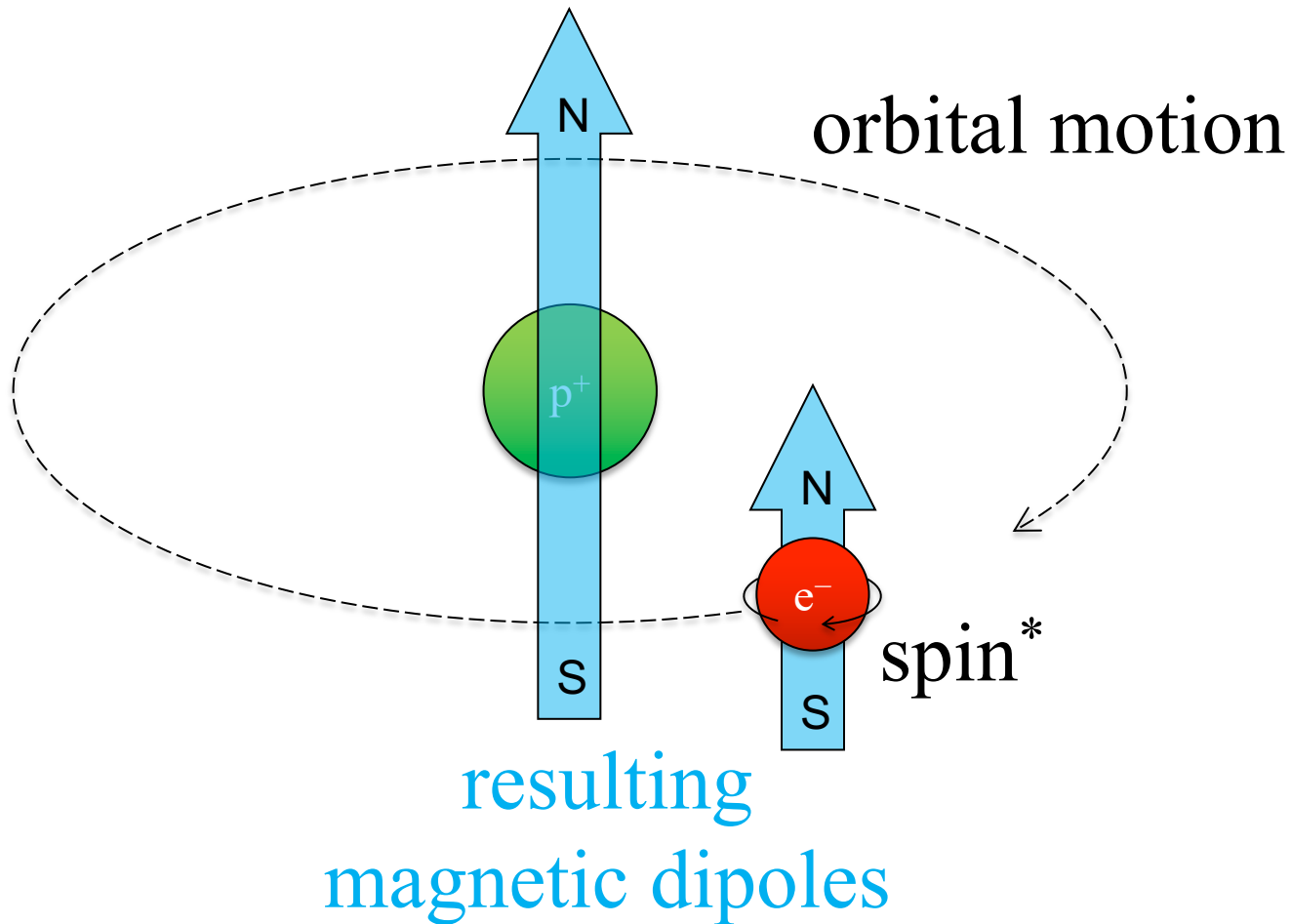
	The student will be able to:	HW:
1	Define and illustrate the basic properties of magnetic fields and permanent magnets: field lines, north and south poles, magnetic compasses, Earth's magnetic field.	 1 – 2
2	Solve problems relating magnetic force to the motion of a charged particle through a magnetic 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 – 39
6	Qualitatively describe and model behavior of magnetic materials using concepts of domains, ferromagnetism, paramagnetism, and diamagnetism.	40 – 44

Ferromagnetism

- Iron, nickel, cobalt, gadolinium, and certain alloys can produce relatively strong magnetic fields intrinsically – such materials are said to be **ferromagnetic**.
- Any “permanent magnet” has this property and requires no current or external power supply.
- The domain theory is a useful model to explain and understand the origin of these magnetic fields.

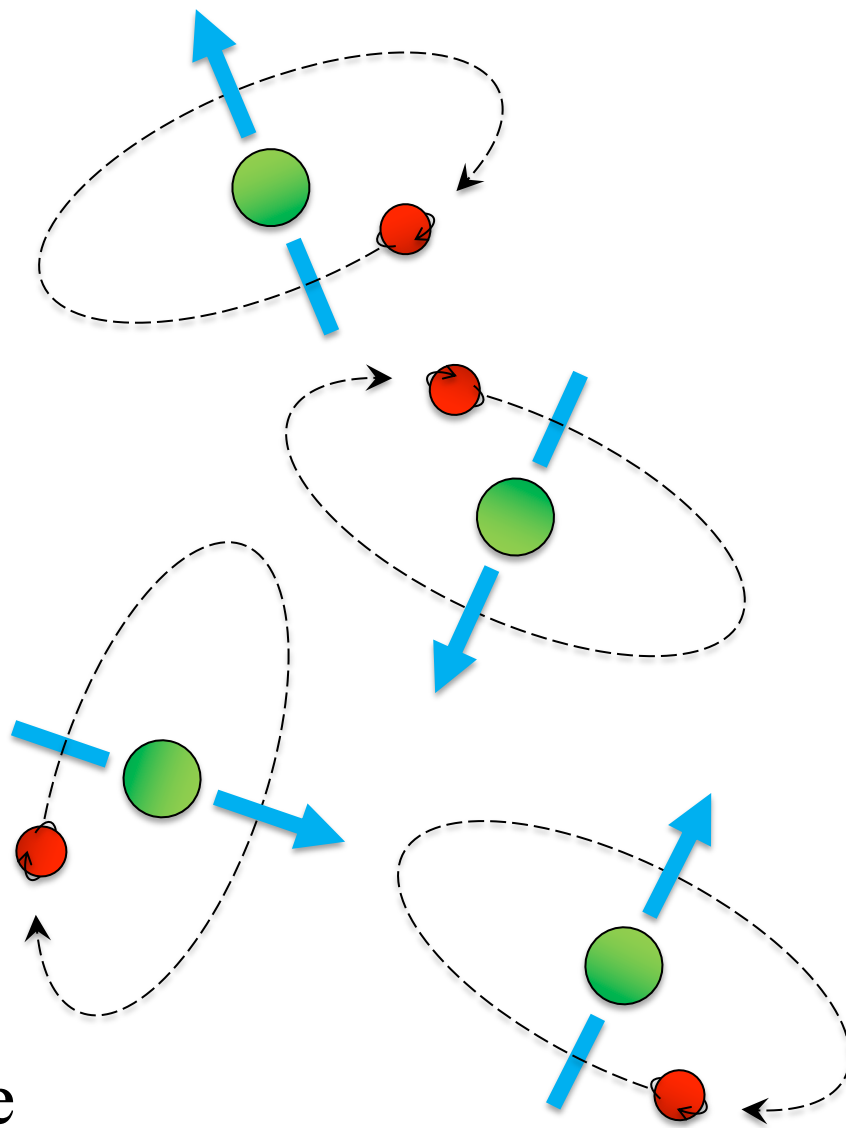
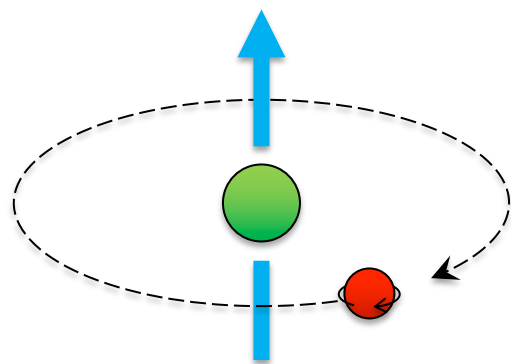
Domains

- Even without an external source of current all matter contains moving charges – electrons.
- Electrons orbit the nucleus and have a property called “spin” – both of which essentially equate with tiny loops of current. Electrons produce magnetic dipoles.
- In ferromagnetic materials electrons within a particular “grain” or “domain” tend to have dipoles that are aligned. The domain thus has a net dipole in a particular direction.



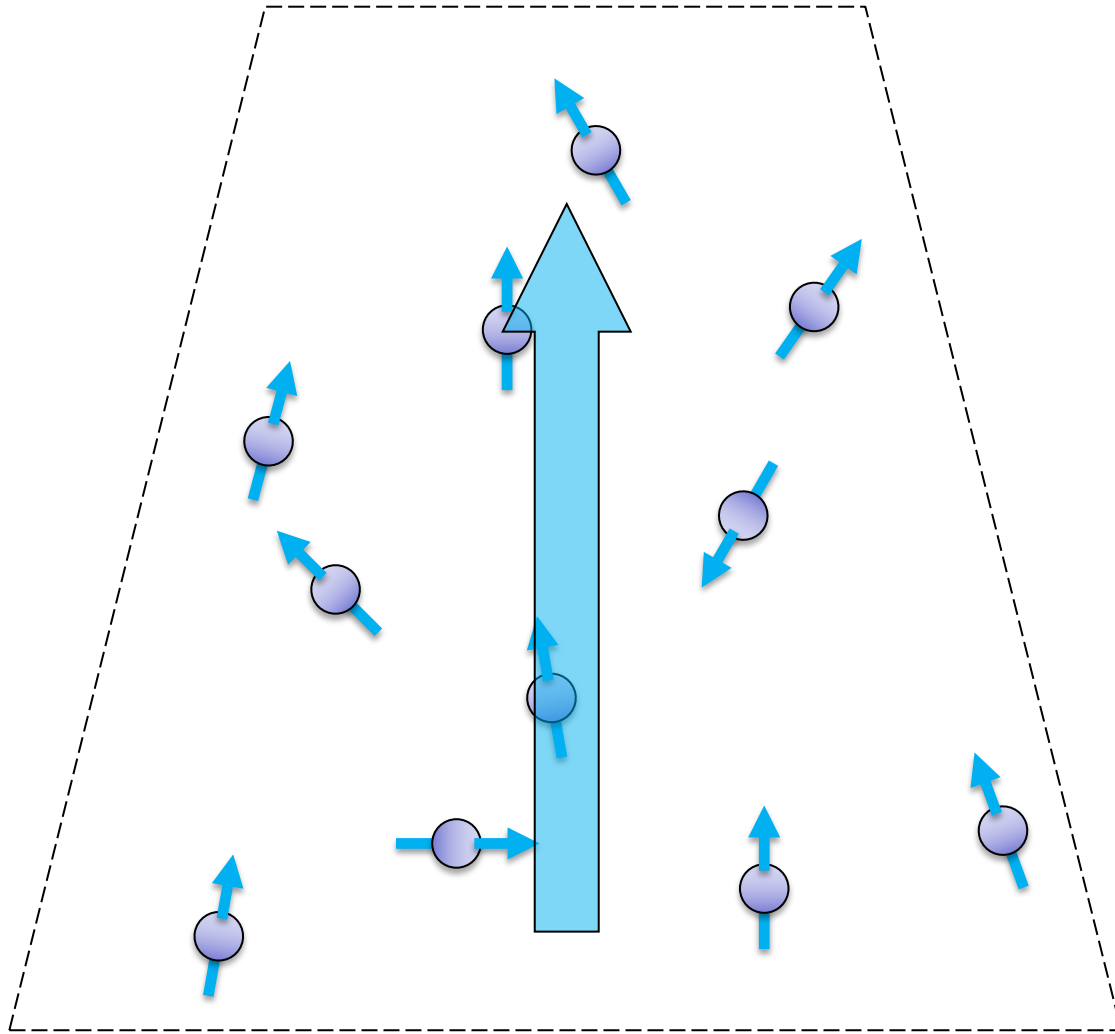
*the quantum property “spin” can be *imagined* as the spinning of the particle but it is not thought to be an *actual* motion

Now imagine
multiple atoms –
each with a dipole:

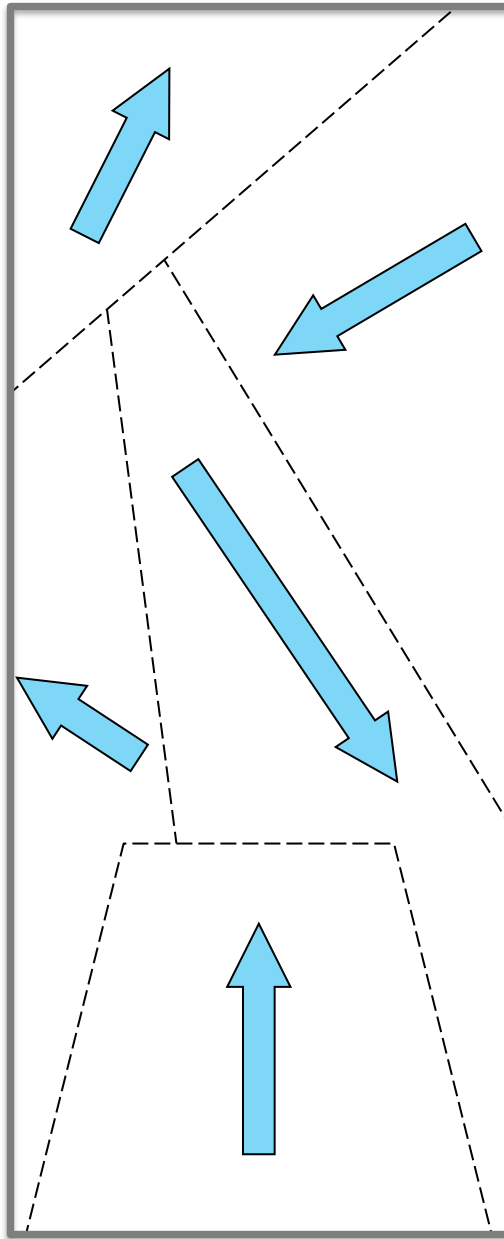


If free to move,
the two in the middle
would tend to flip over and
align with the other three!

Within a small region of a material the dipoles may be oriented with a preferential direction, resulting in the production of a net magnetic field within that domain.

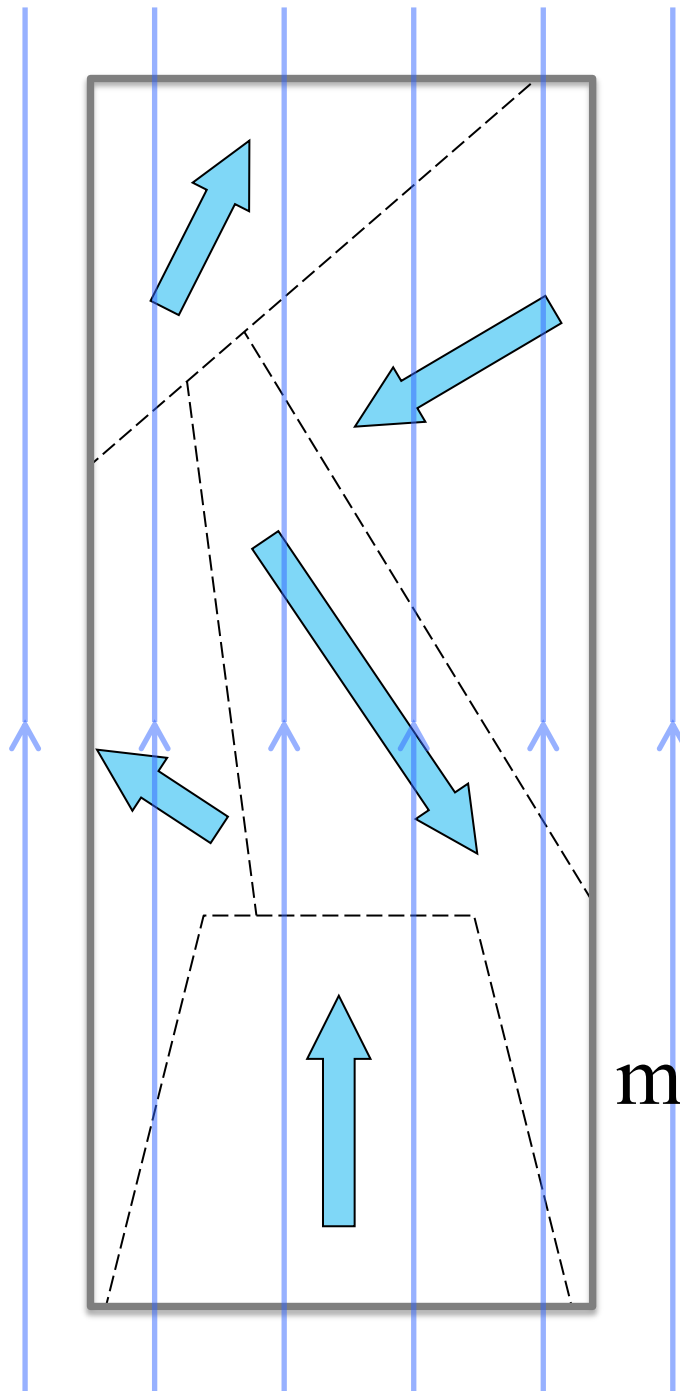


Ferromagnetic domains may be randomly oriented, in which case the object is not observed to produce a net field...

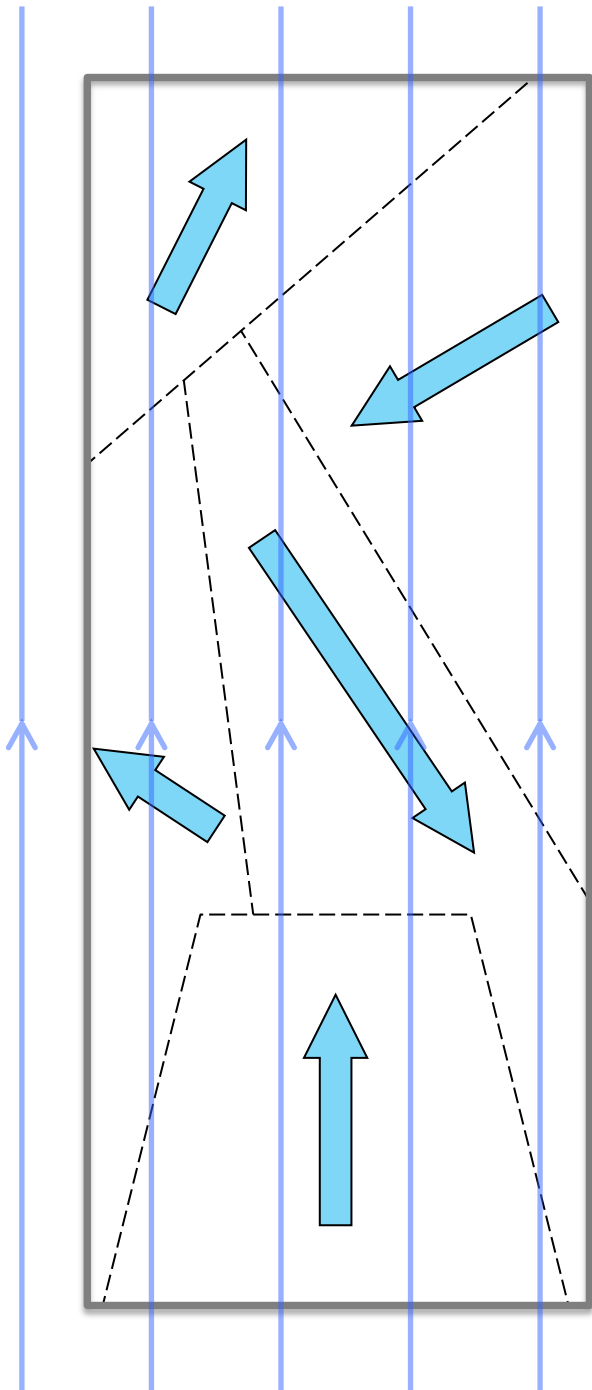


...so the object is not a “magnet”.

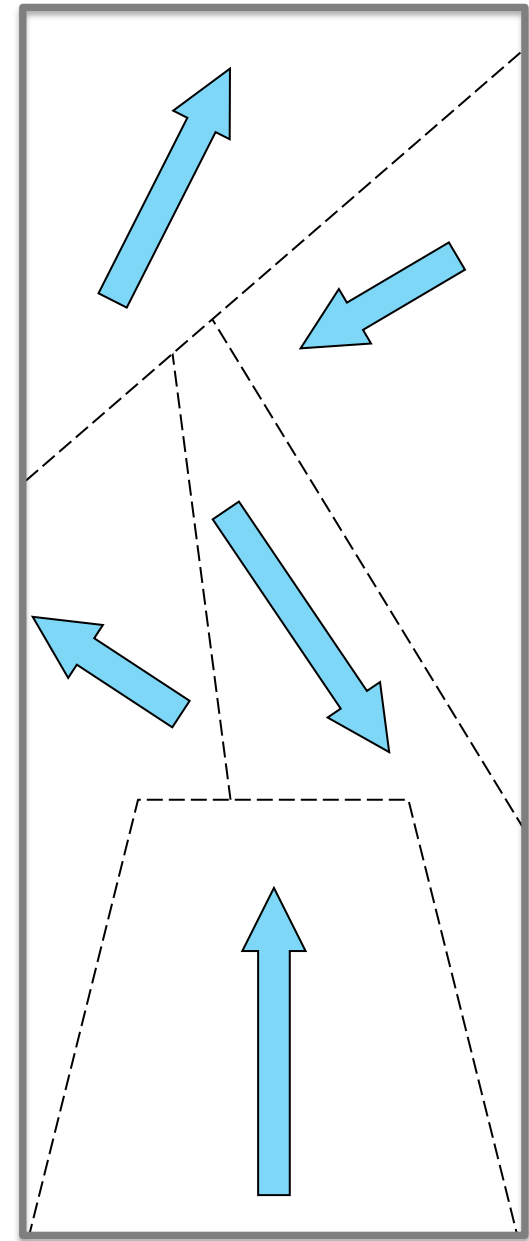
An external magnetic field can cause the domains to change...



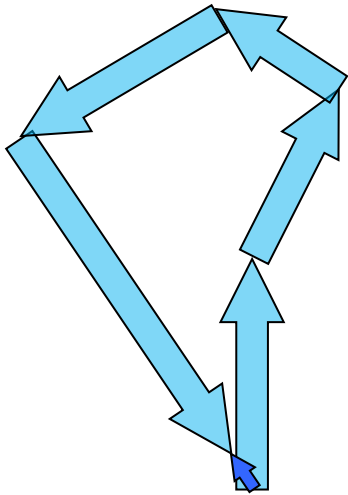
...and ferromagnetic material may retain a net magnetic field as a result.



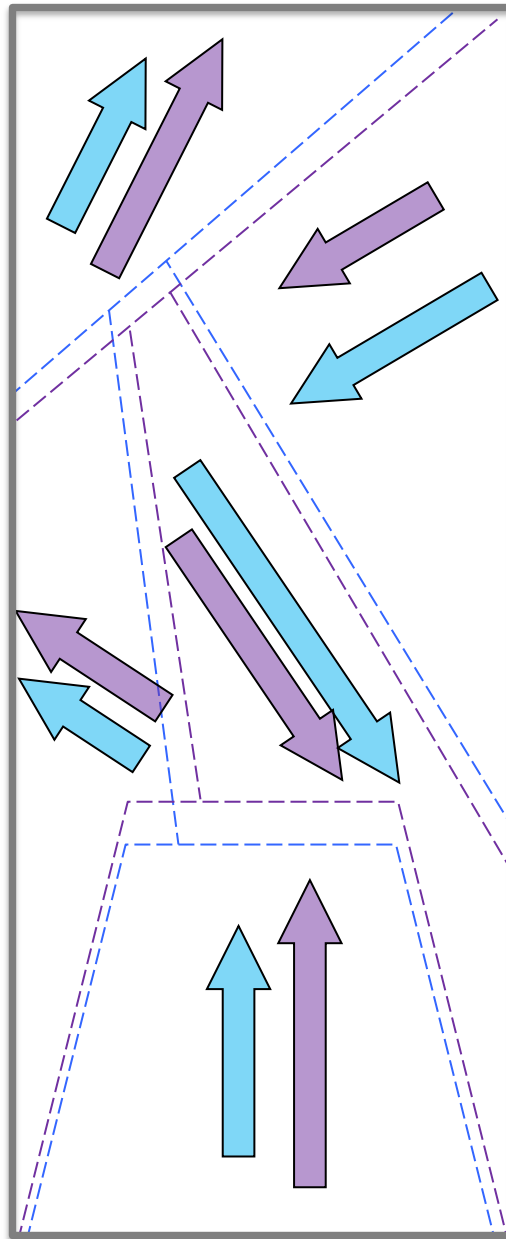
Note that domains pointing up get larger and those pointing down get smaller:



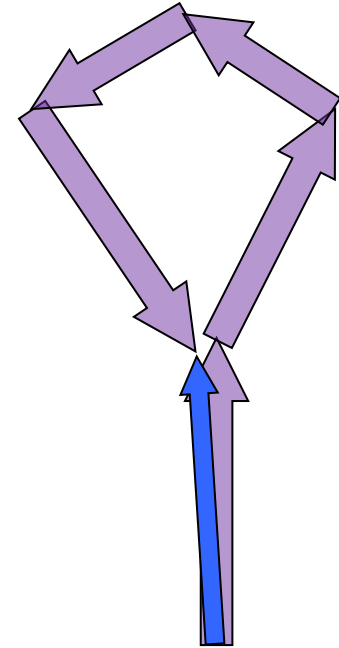
before:



net field was negligible



after:



net field is significant, object is now a "magnet"

Permanent Magnets

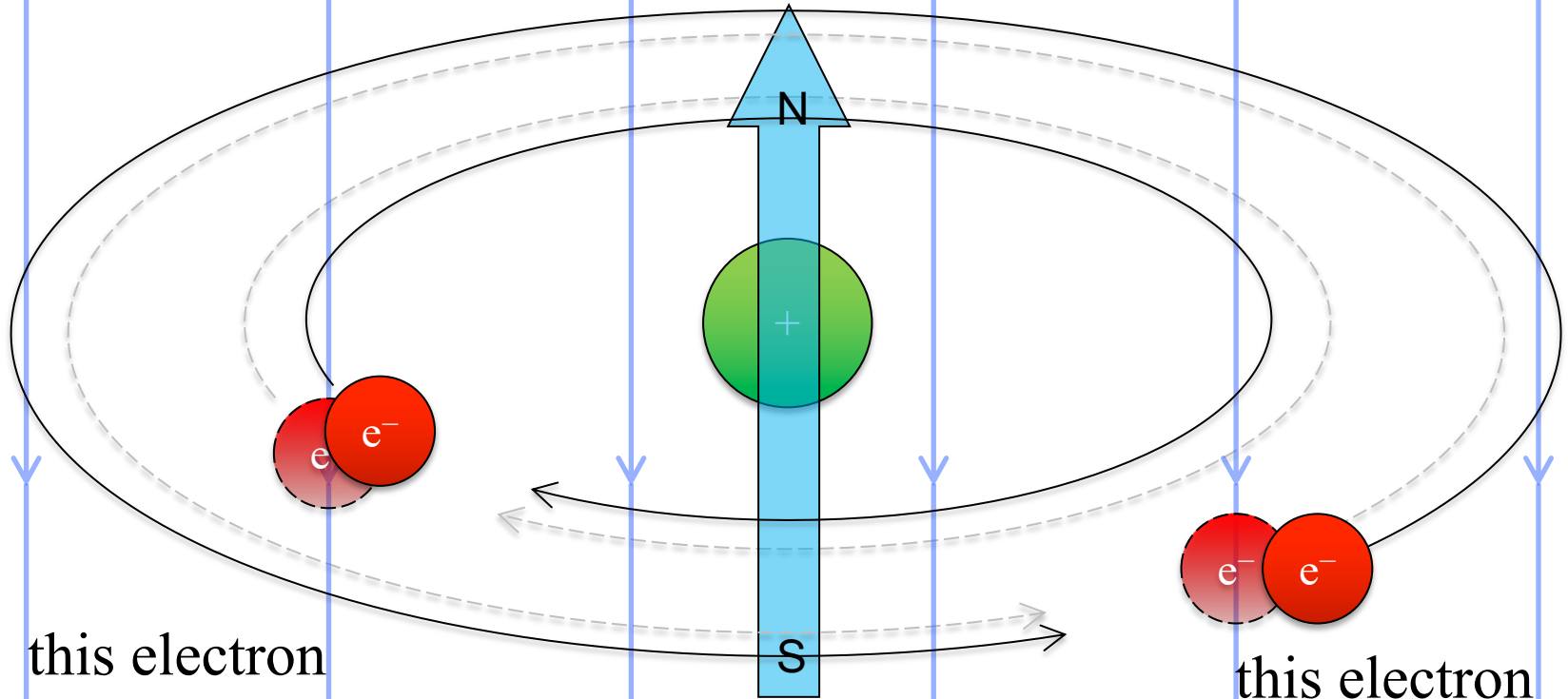
- A permanent magnet has domains with dipoles that are mainly aligned with one another.
- If heated to a high enough temperature (the Curie point) the domains will tend to become disorganized and become randomly oriented, which removes the “permanent” field!
- A sudden hard impact can also cause the domains to become randomized.

Paramagnetism

- Some materials exhibit a *very weak* behavior similar to ferromagnetic materials. Aluminum is an example.
- Such materials will temporarily be very slightly attracted to a magnet or tend to align with an external magnetic field.
- There is no tendency or capability to form domains or retain a net intrinsic magnetic field.

Diamagnetism

- All materials exhibit a *very weak* behavior opposite to ferromagnetic materials.
- However this property is sometimes overwhelmed by paramagnetism or ferromagnetism.
- Water is an example material for which diamagnetism is the dominant magnetic property.
- The presence of an external magnetic field causes electrons orbiting in one direction to gain speed and electrons orbiting in the opposite direction to lose speed. This creates an opposing magnetic field – normally a very small effect.



this electron gains speed

this electron loses speed

net effect is to produce an opposing magnetic field

B_{external}

Frog levitated by
diamagnetic effect on water
– magnetic field 16 T!



image credit: High Field Magnetic
Laboratory, Radboud University

Super conductor levitated by
a simple permanent magnet
(a few mT) – can be said to
be perfectly diamagnetic.

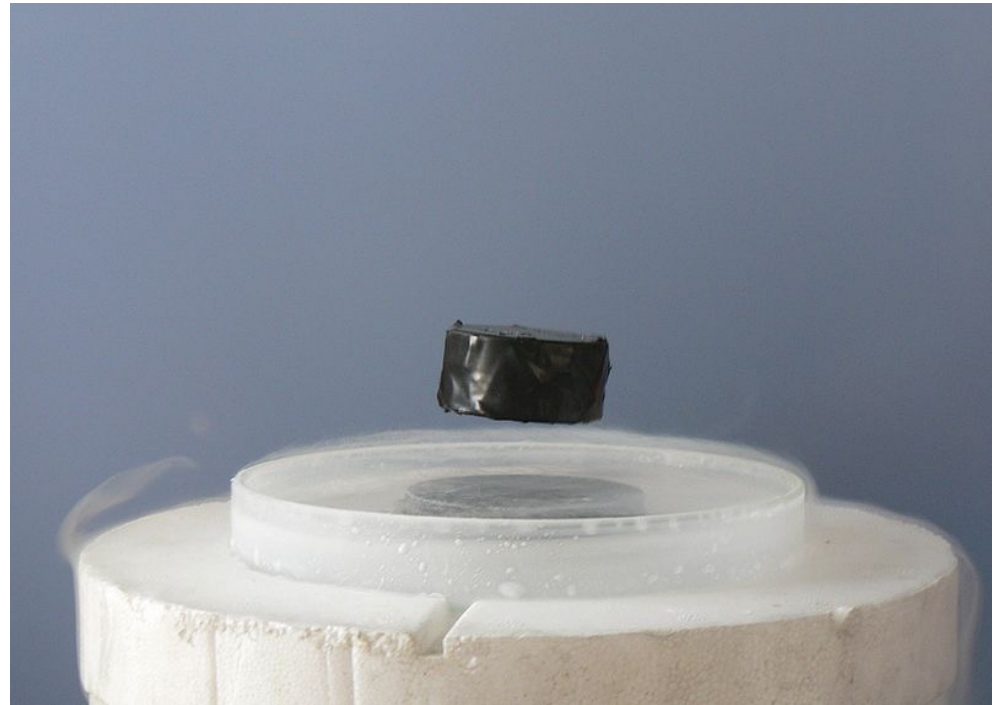


image credit: Mai-Linh Doan, Wikipedia