Magnetism

I. Magnetic Field
- units, poles
- effect on charge

II. Magnetic Force on Current
- parallel currents, motors

III. Sources of Magnetic Fields
- Ampere's Law
- **magnetism in matter**

IV. Magnetic Induction
- Faraday's Law
- Lenz's Law

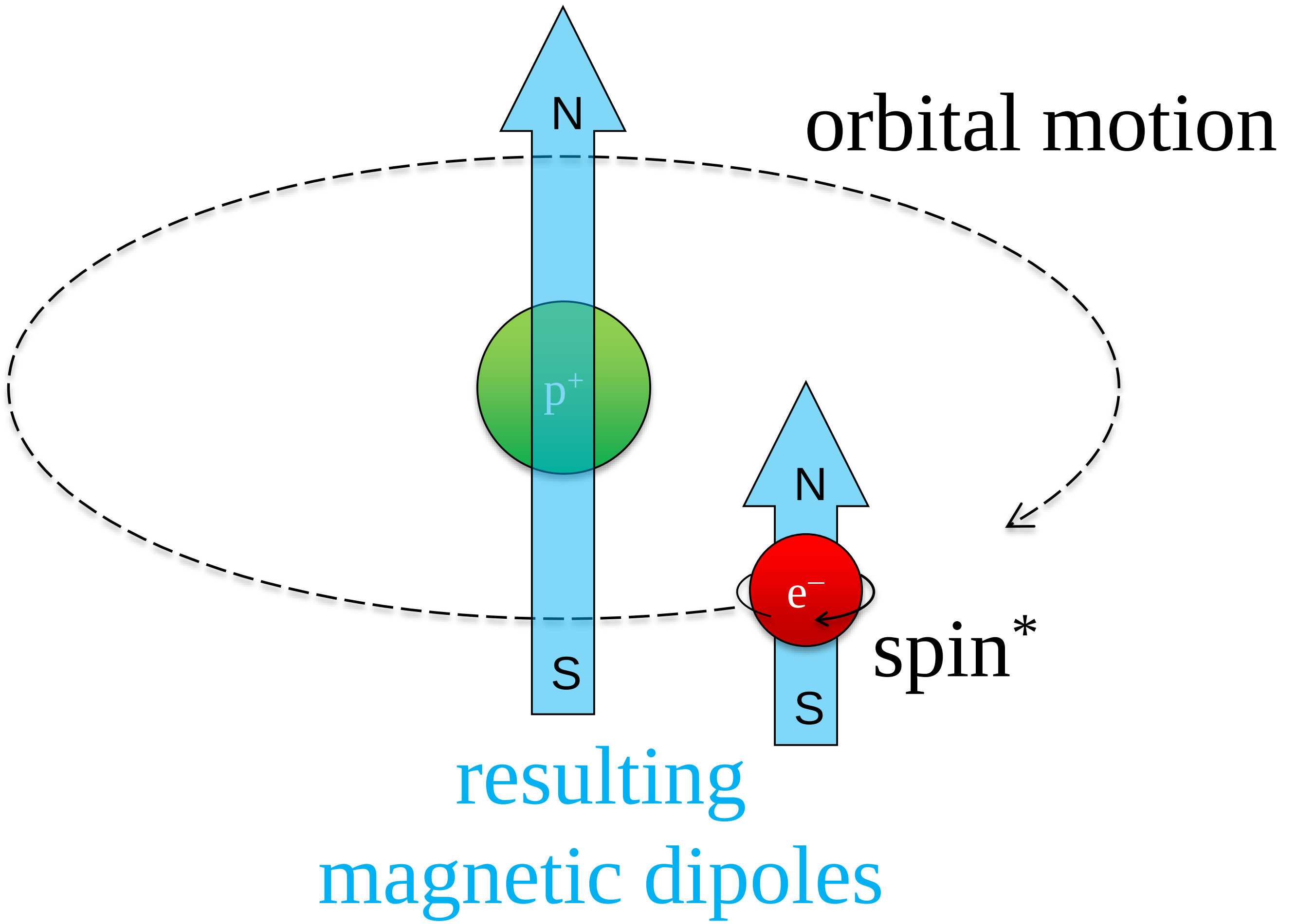
	The student will be able to:	HW:
1	Define and illustrate the basic properties of magnetic fields and permanent magnets: field lines, north and south poles, magnetic compasses, Earth's magnetic field.	✓ 1 – 4
2	Solve problems relating magnetic force to the motion of a charged particle through a magnetic field, such as that found in a mass spectrometer.	✓ 5 – 11
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.	✓ 12 – 18
4	State and apply relation between magnetic field and position for a long current carrying wire and solve related problems.	✓ 19 – 25
5	Qualitatively describe and apply properties of magnetic dipole fields generated by loops of current and model behavior of magnetic materials using domains, ferromagnetism, paramagnetism, and diamagnetism.	26 – 30
6	State and apply Faraday's Law and Lenz's Law and solve problems involving induced emf and magnetic flux.	31 – 38

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.

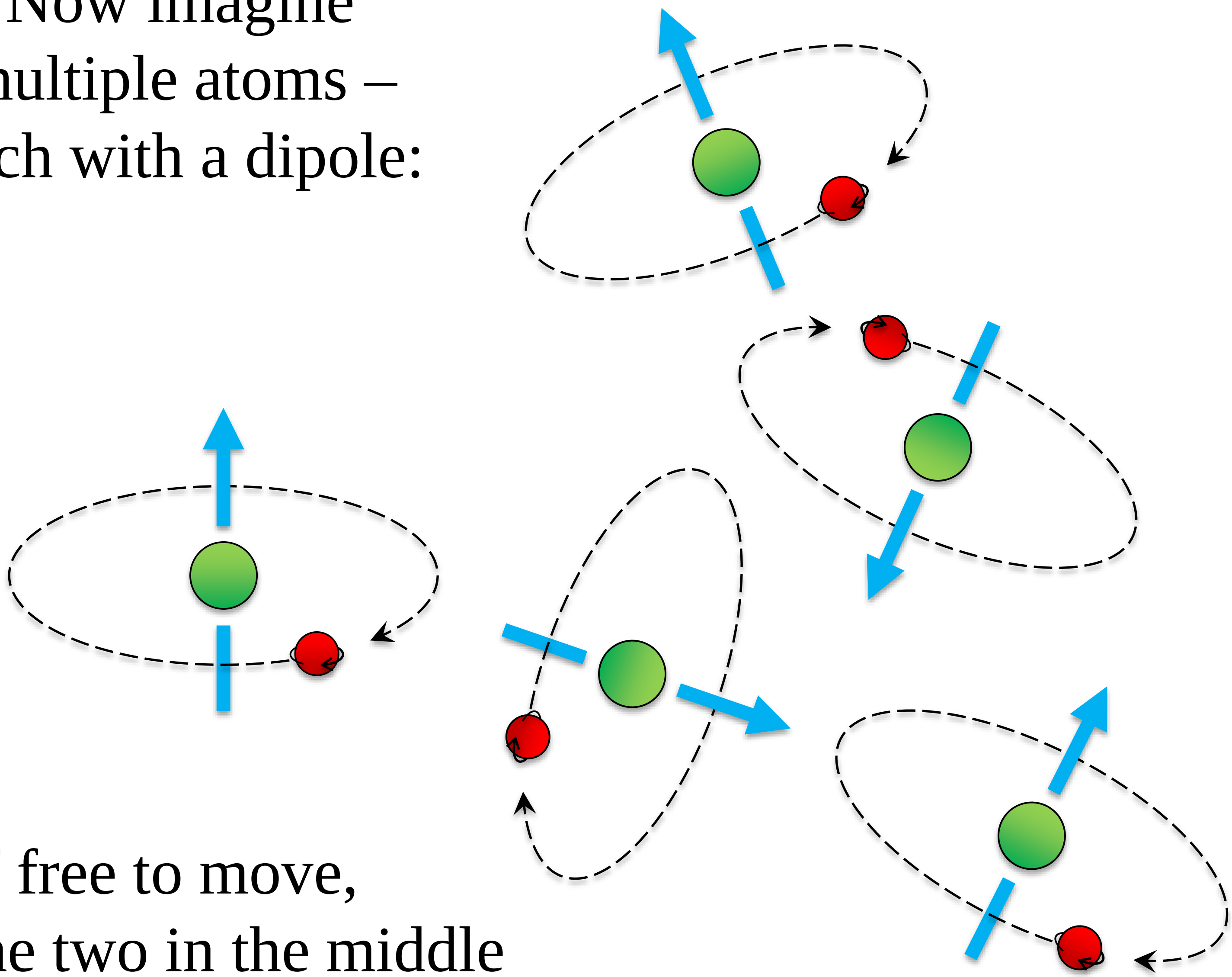
Domains

- 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.



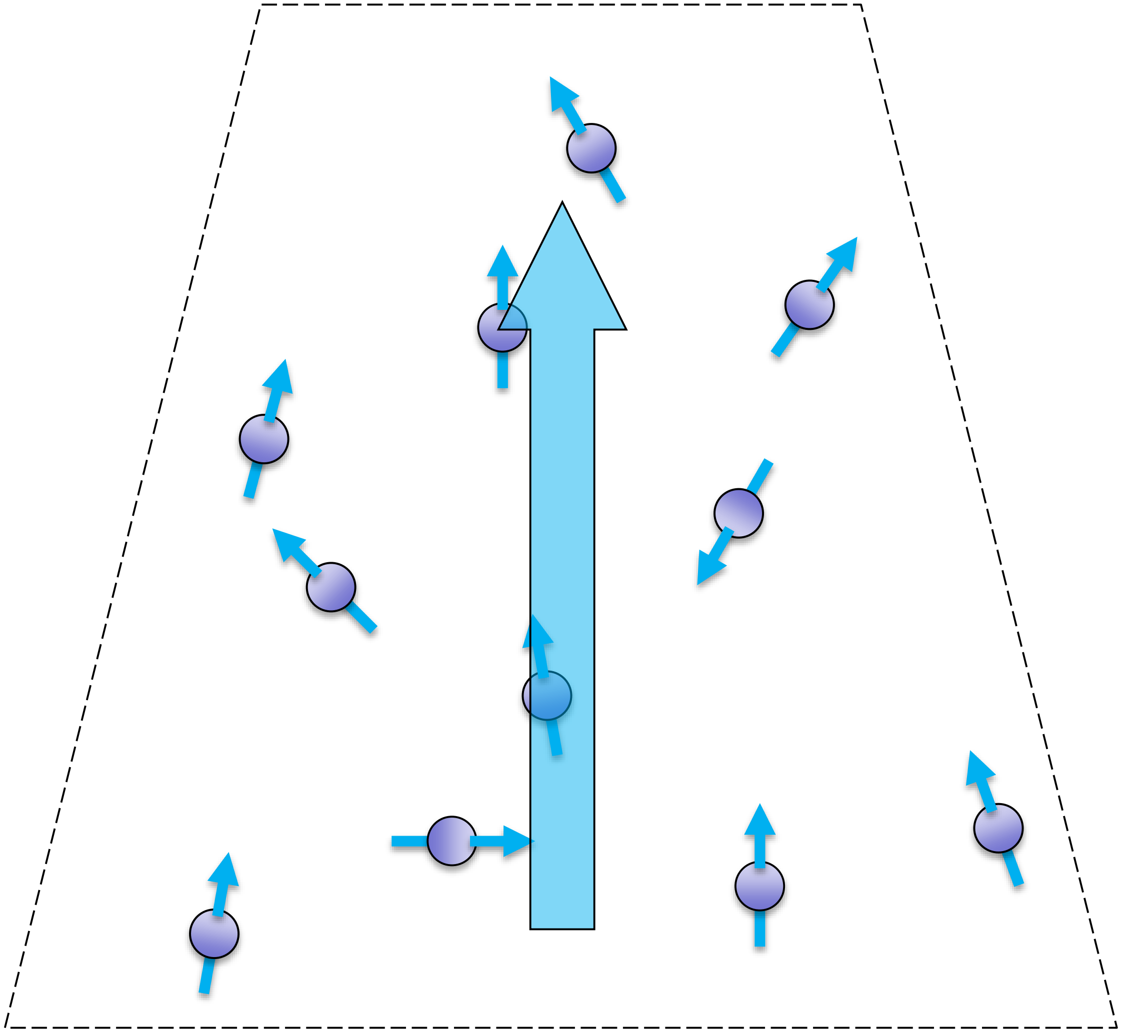
*the quantum property "spin" can be *imagined* as the spinning of the particle but it is not thought to be an *actual* motion

Now imagine multiple atoms – each with a dipole:

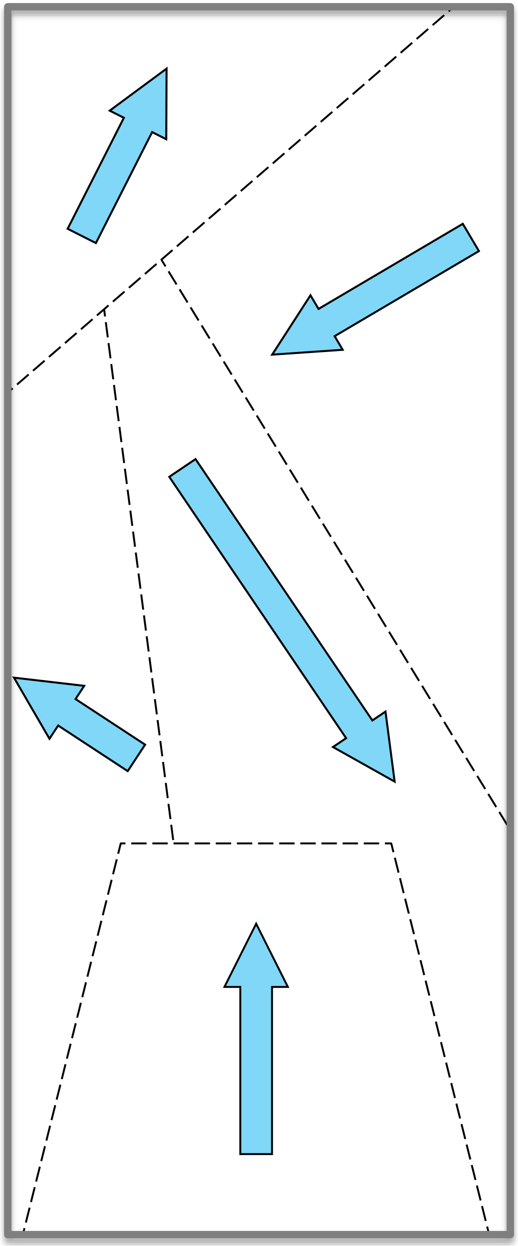


If free to move, the two in the middle would tend to flip over and align with the other three!

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.

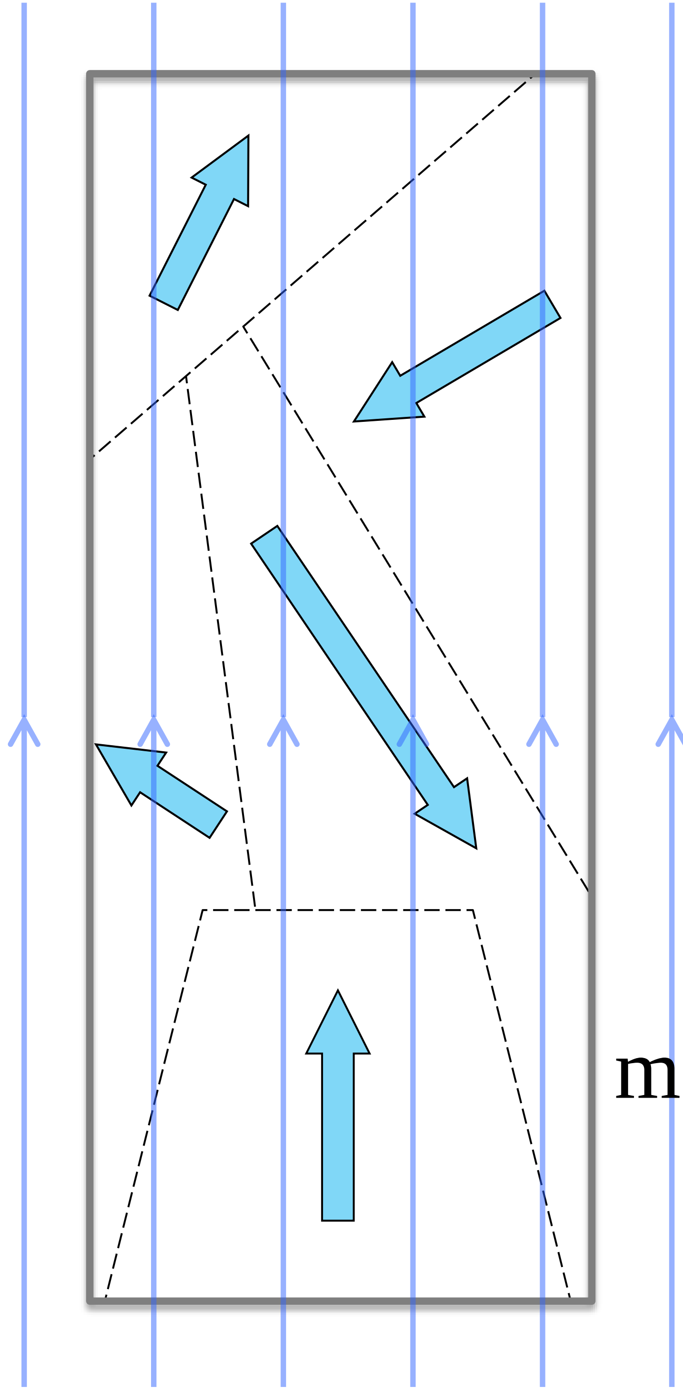


Ferromagnetic domains may be randomly oriented, in which case the object is not observed to produce a net field…



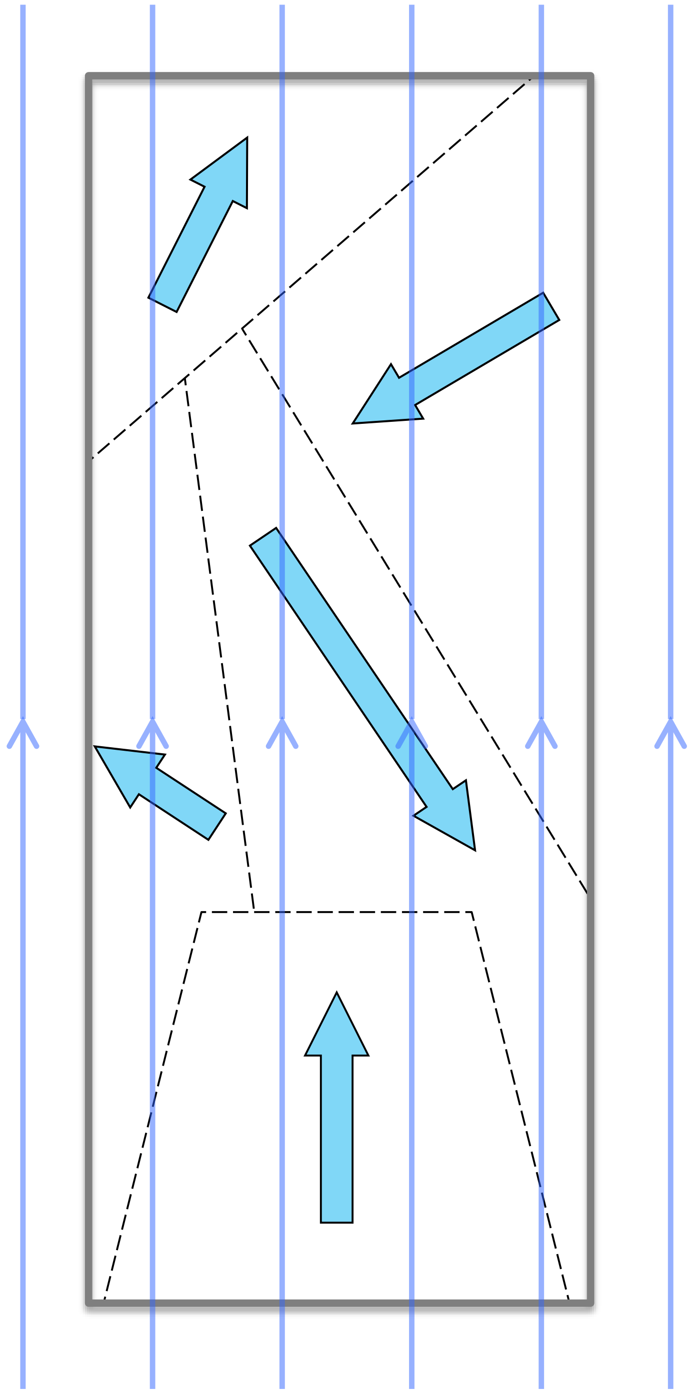
…so the object is not a “magnet”.

An external magnetic field can cause the domains to change…

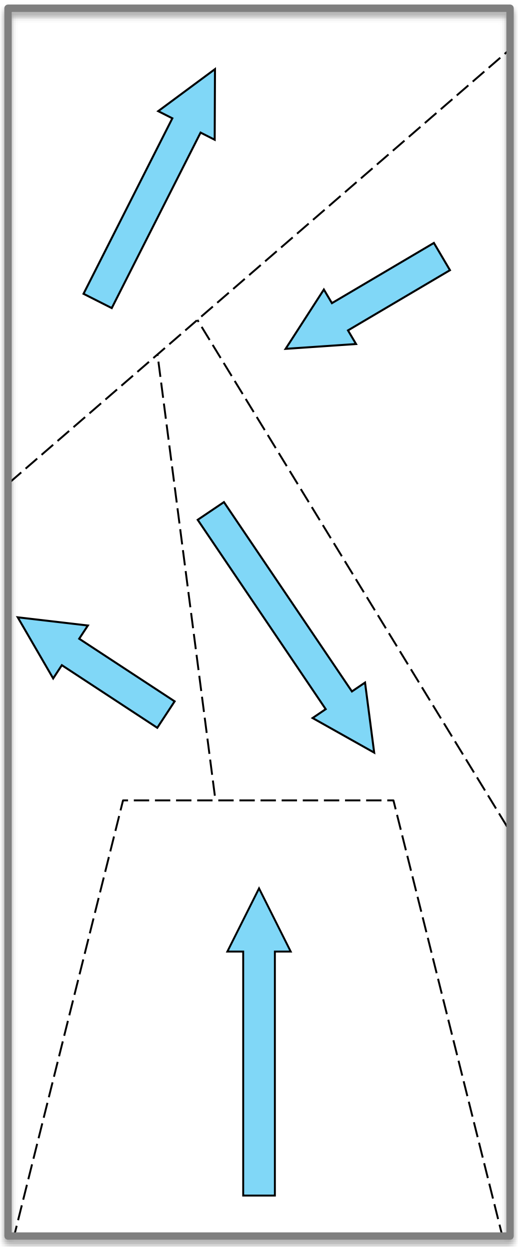


…and ferromagnetic material may retain a net magnetic field as a result.

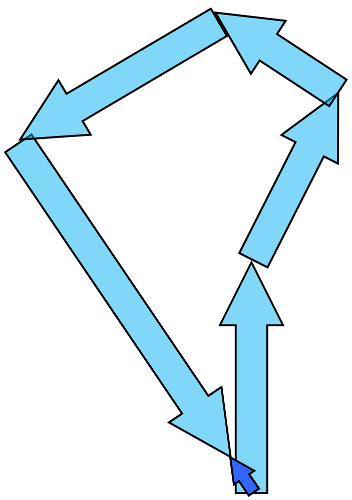
Note that domains pointing up get larger and those pointing down get smaller:



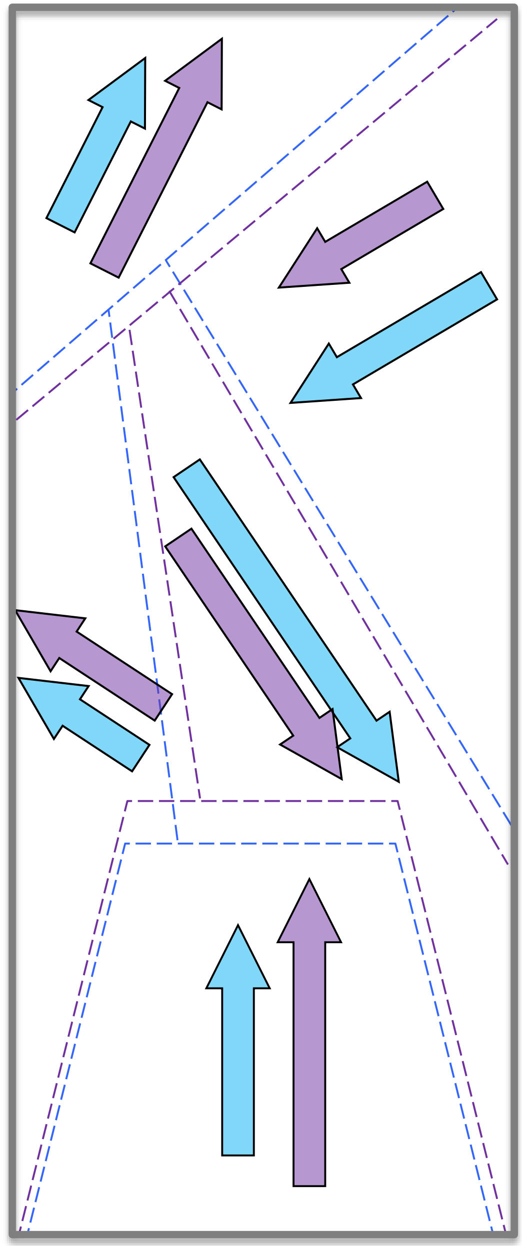
afterward



before:



net field was negligible



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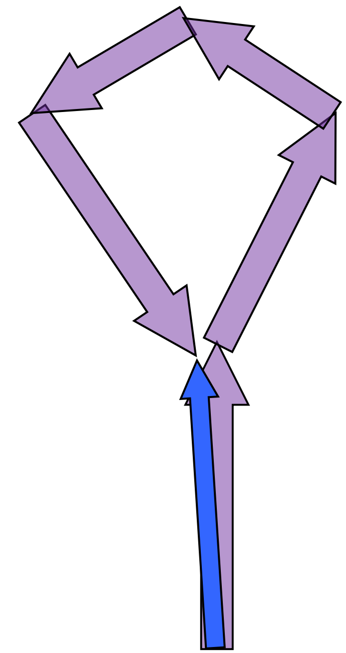


net field is significant, object is now a “magnet”

Permanent Magnets

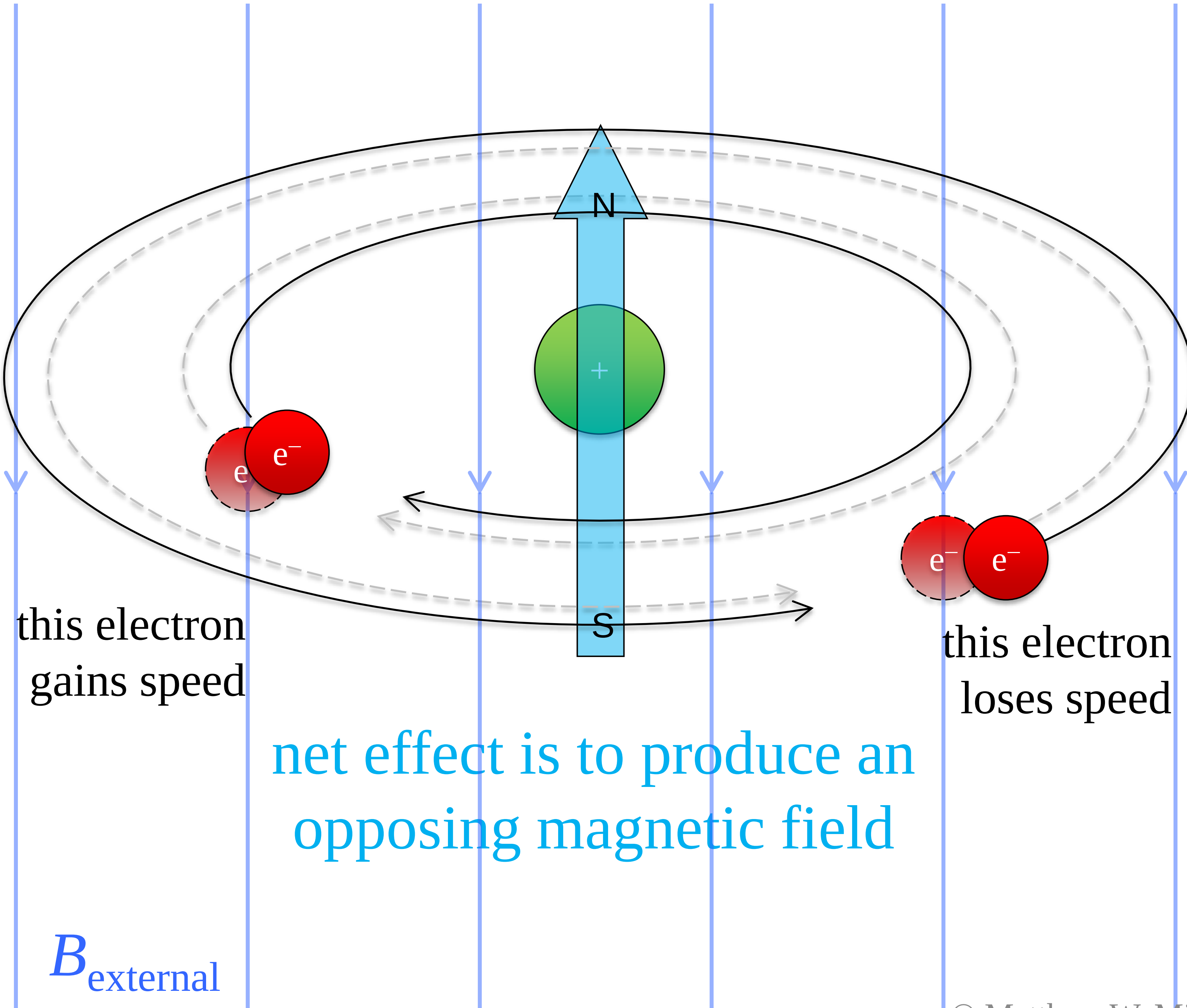
- A permanent magnet has domains with dipoles that are mainly aligned with one another.
- If heated to a high enough temperature (the Curie point) the domains will tend to become disorganized and become randomly oriented, which removes the "permanent" field!
- A sudden hard impact can also cause the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


N
S
e⁻
e⁻
e⁻
e⁻
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.

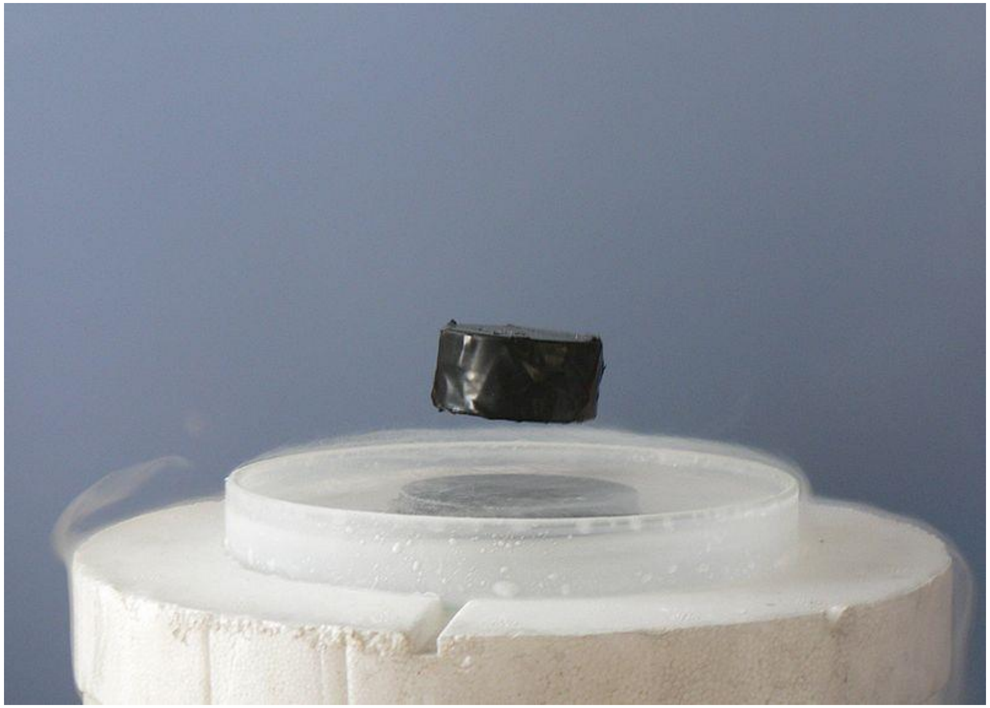


image credit: Mai-Linh Doan, Wikipedia