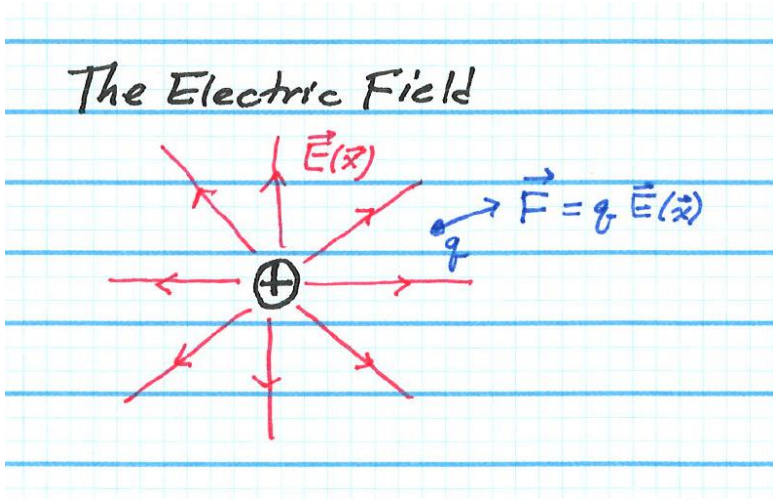
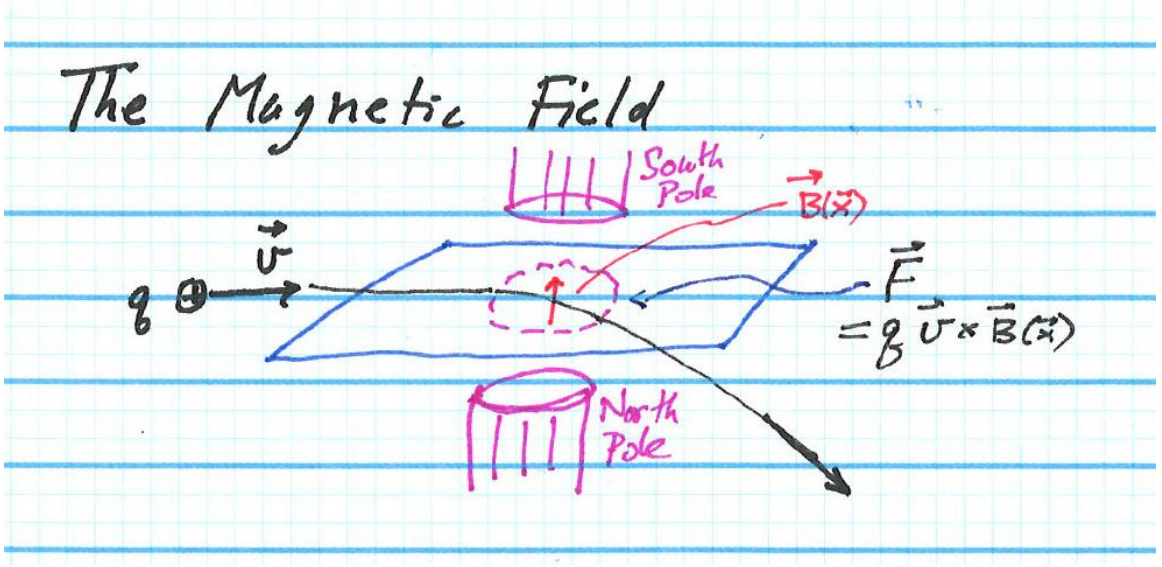
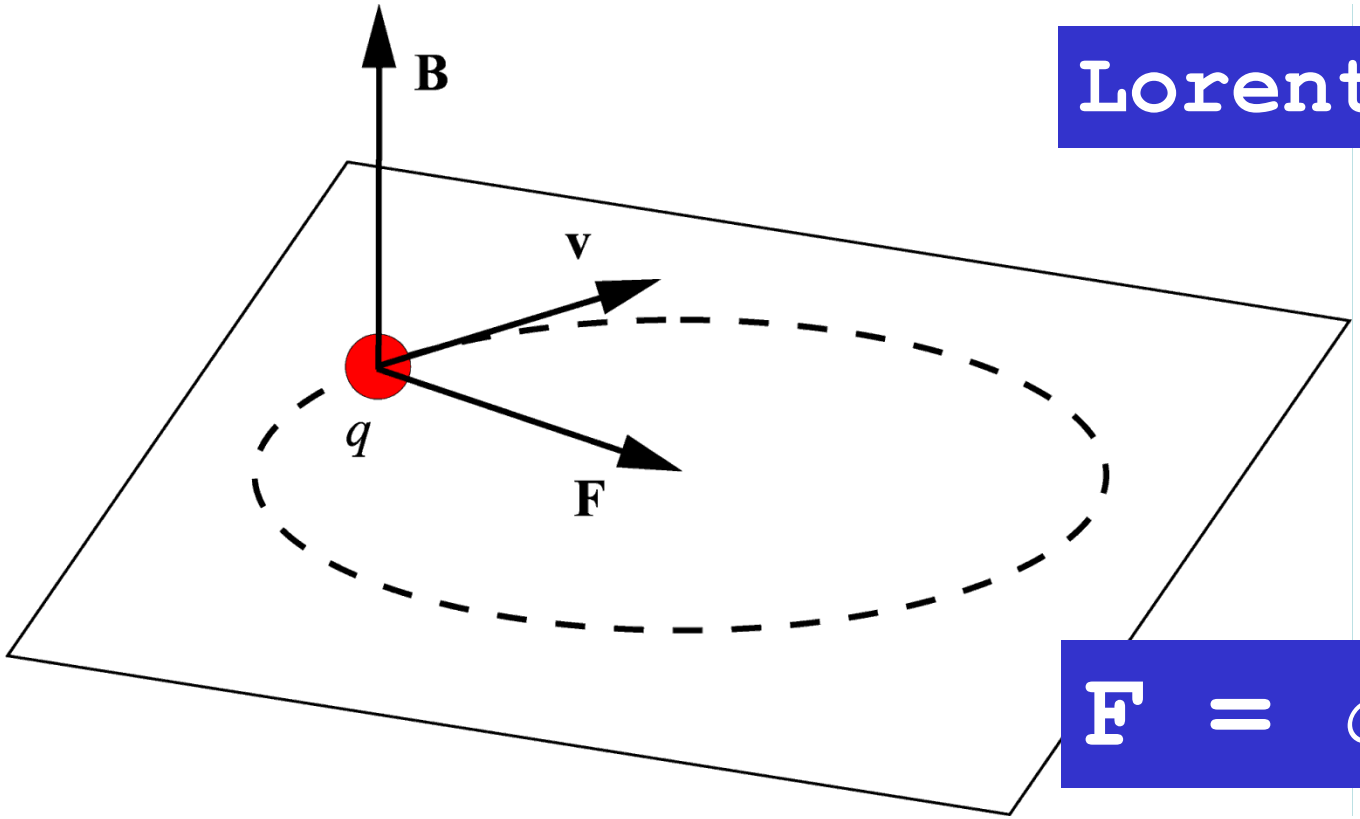
The Magnetic Field – part 2





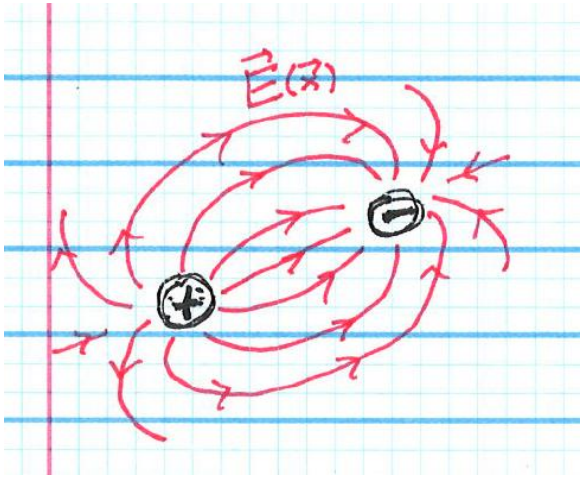
Cross products are necessary in the theory of magnetism because the directions of magnetic forces and fields are sideways.



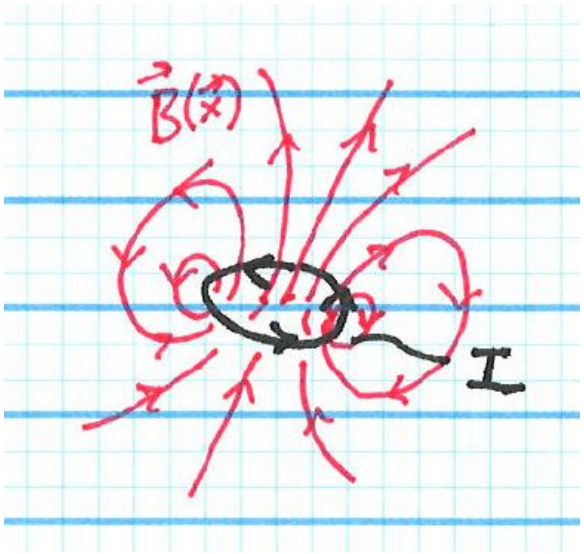
Lorentz force

$$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$$

Electric charges create an electric field, E(x).

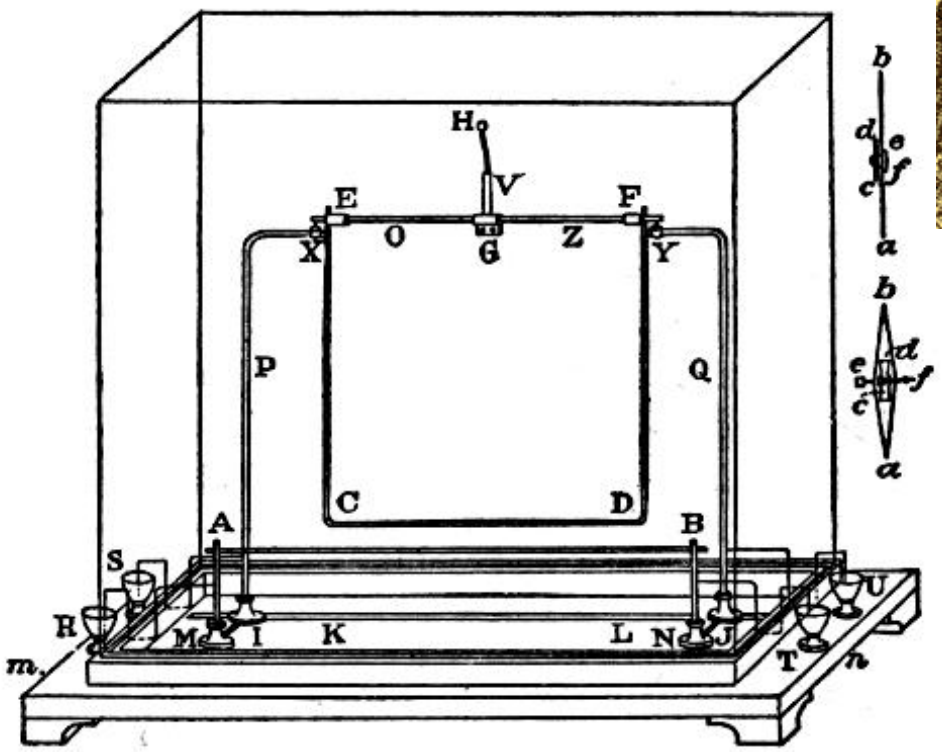


What creates a magnetic field, B(x)?



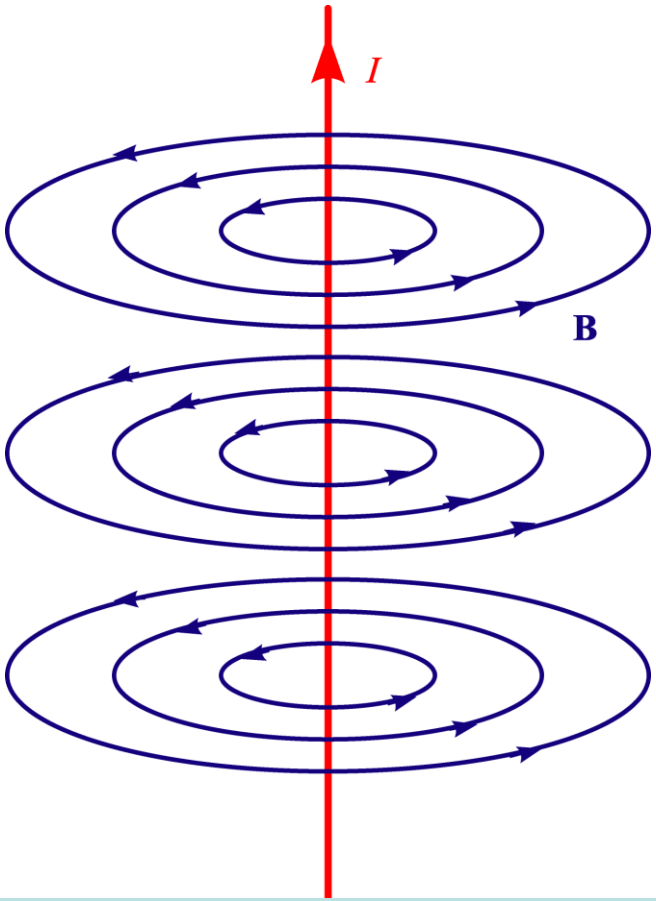
Ampère's Law

Hans Christian Oersted (1820)
Electric current *I* produces a magnetic field B

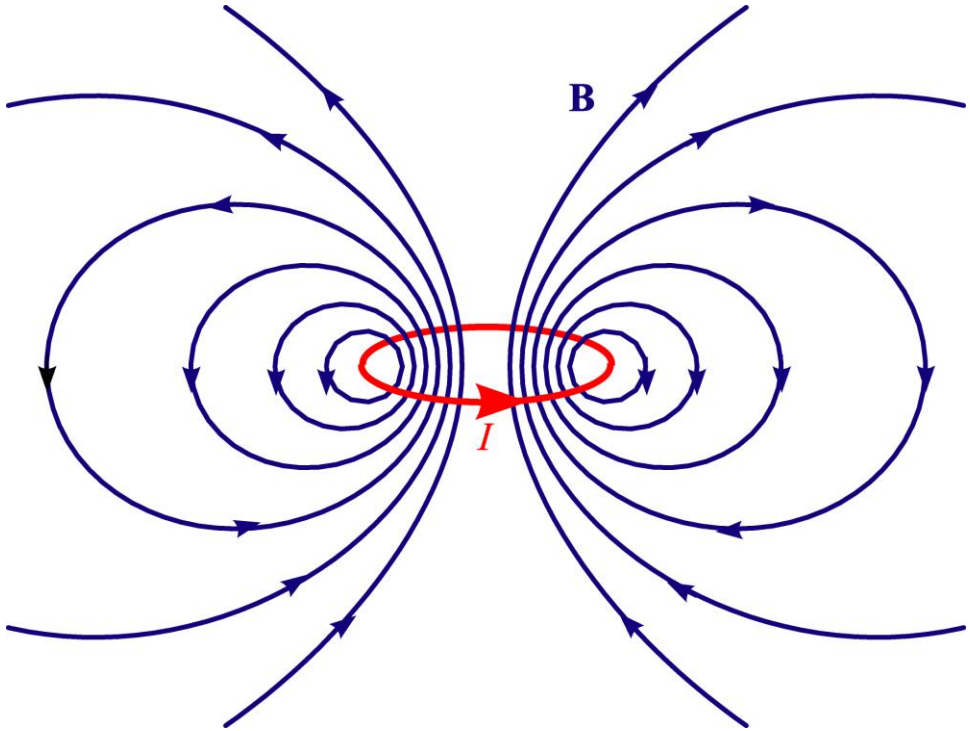


André-Marie Ampère (1820)
The magnetic field curls around the current.

Ampère's law is another application of the right-hand rule: if the thumb of your right hand points in the direction of the current, the fingers curl around in the direction of the magnetic field.

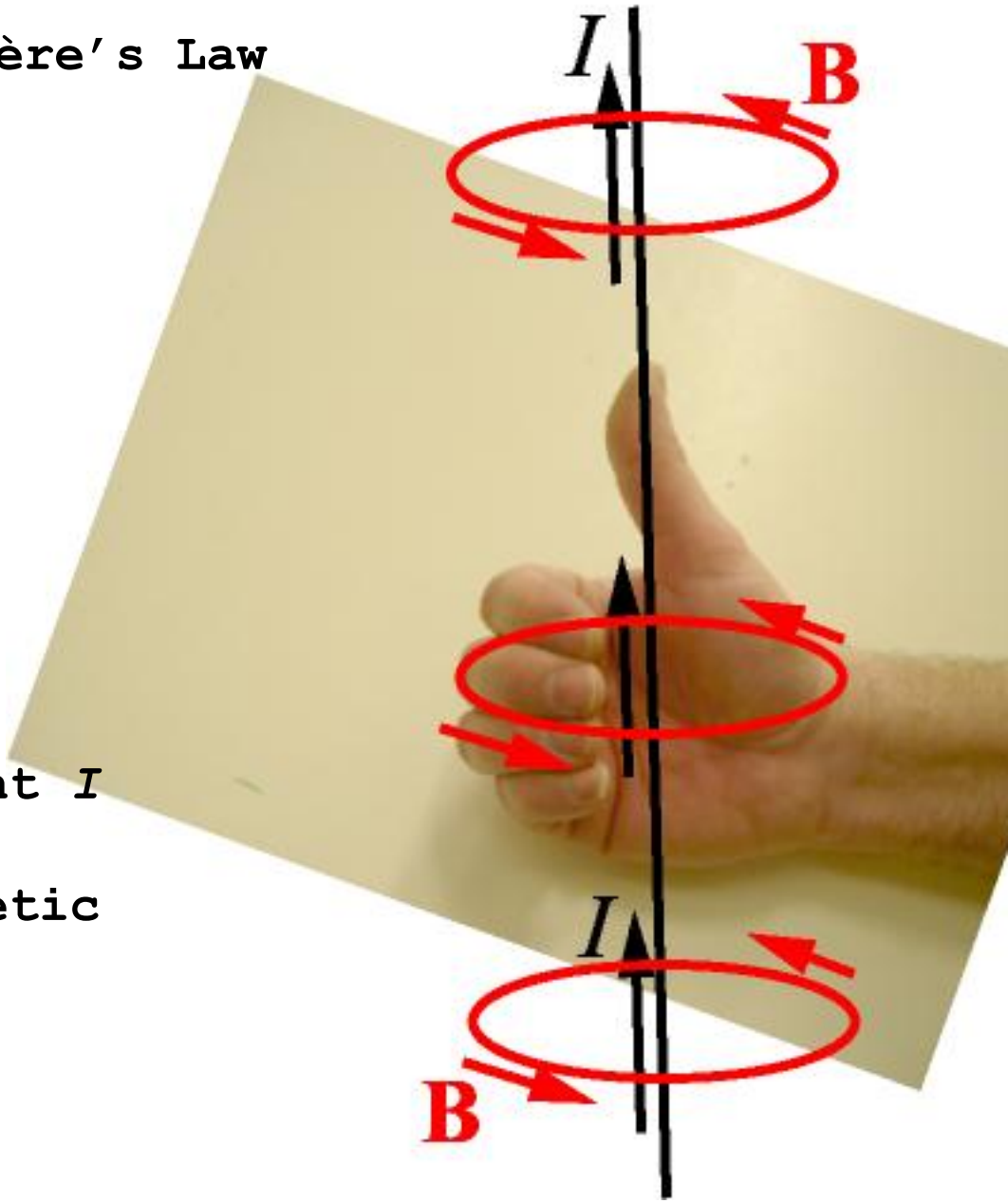


A straight wire creates B, which curls around I



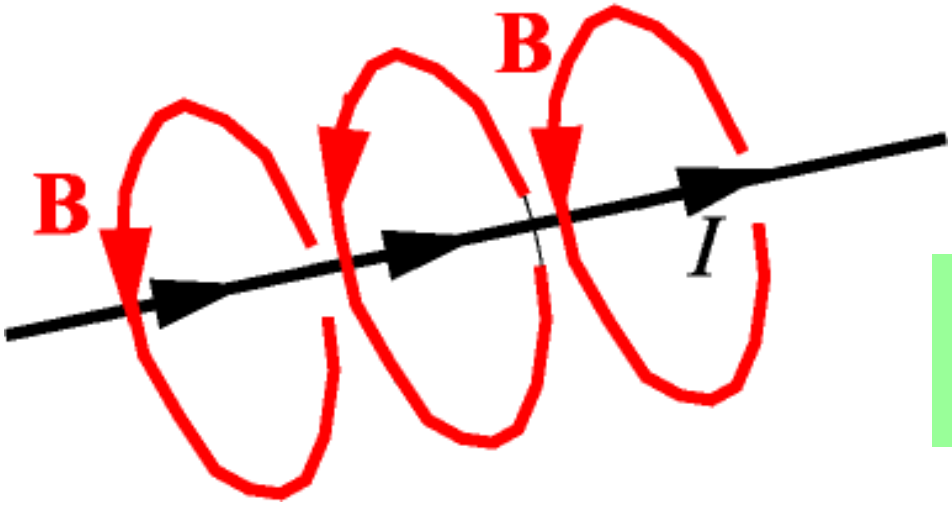
A current loop creates B, which curls around I

Right-hand rule for Ampère's Law



Thumb along the current *I*
➔ fingers curl in the direction of the magnetic field B.

The magnetic field due to a long straight wire



The field curls around the current; right-hand rule!

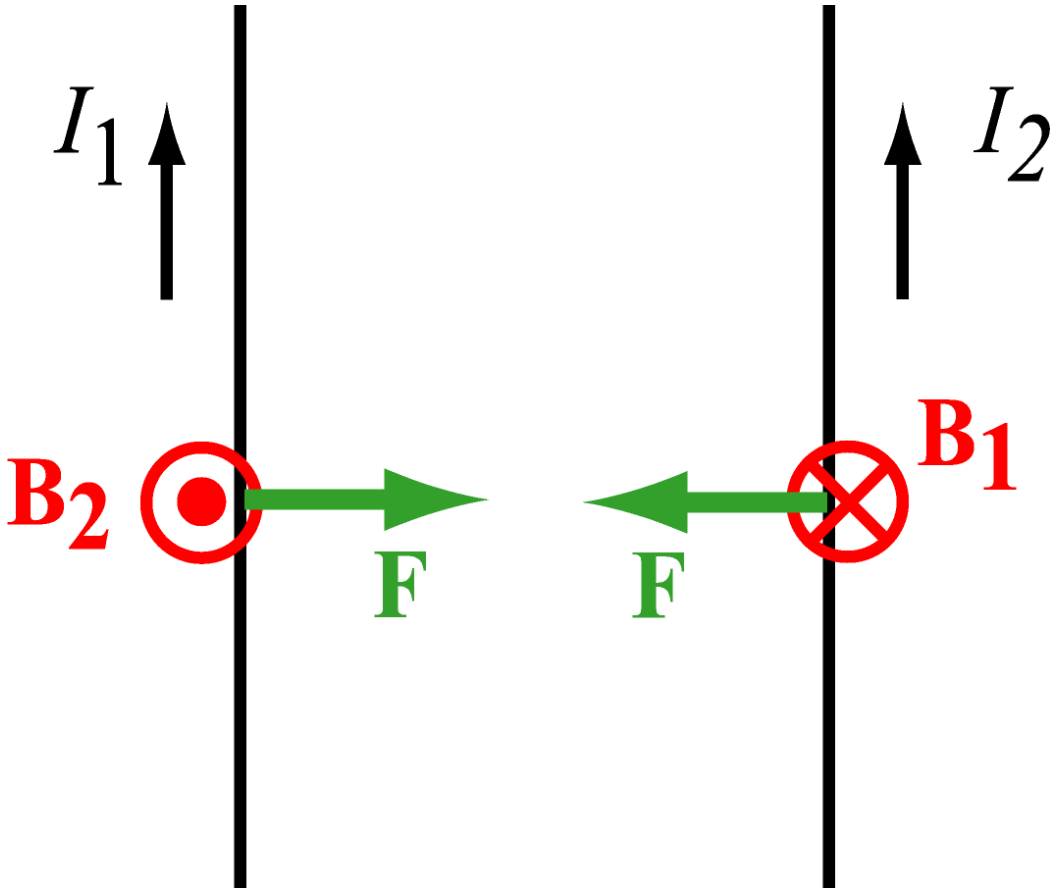
$$\mathbf{B} = \frac{\mu_0 I}{2\pi r}\hat{\phi}$$

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\ m/A}$$

Units:
amp = A : current
meter = m : distance
tesla = T : magn field

The force between current carrying wires …

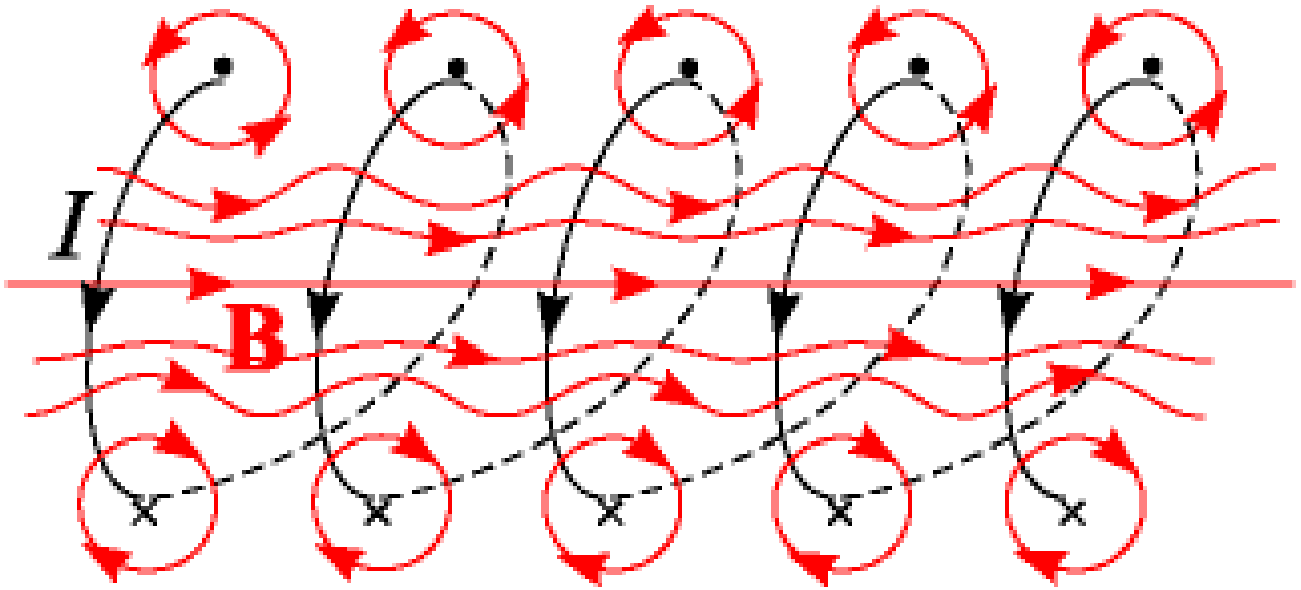
… apply the right hand rule, *twice*



For parallel currents in same direction, there are attractive forces.

The magnetic field of a solenoid

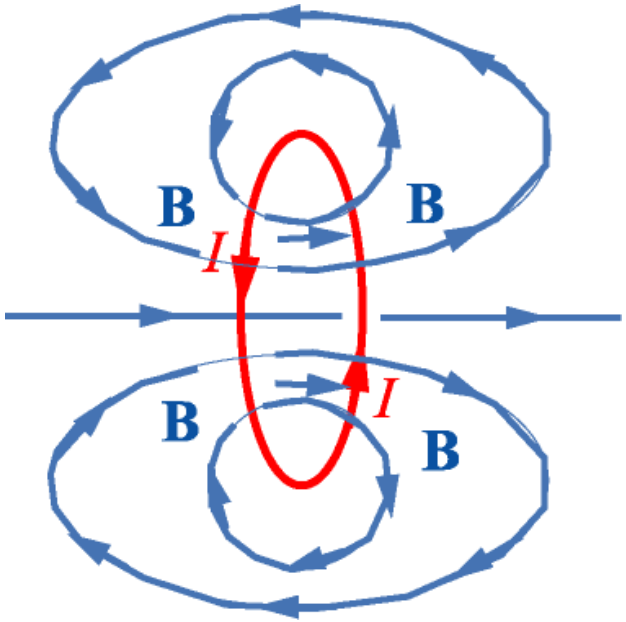
The field curls around the current; right-hand rule!



Inside the solenoid,

$$\mathbf{B} = \mu_0 \frac{N}{L} I \hat{\mathbf{k}}$$

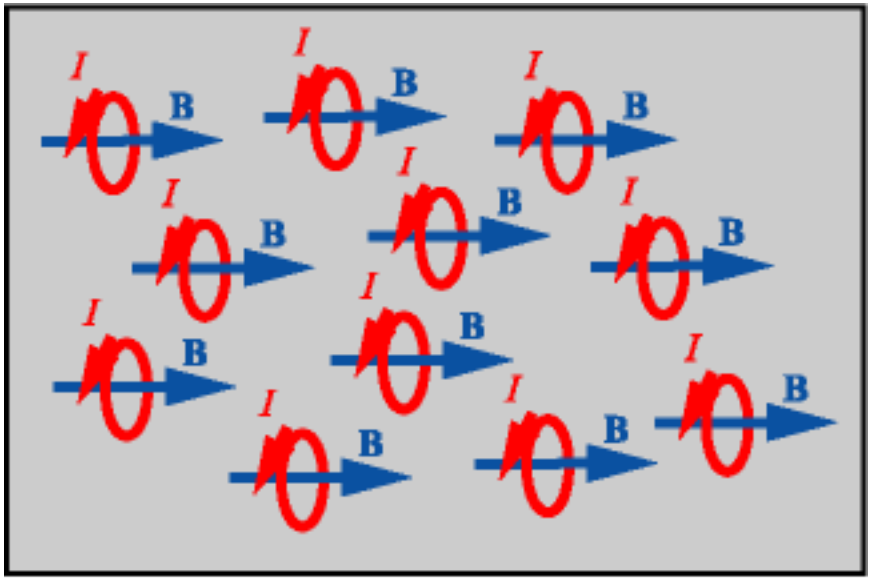
How do *"atomic currents"* make a permanent magnet?



What is a magnet, i.e., a permanent ferromagnet?

The figure to the left shows a single current loop – *the field curls around the current*.

In a ferromagnetic domain of iron, the atomic currents are aligned ➔ a strong magnetic field. Nonmagnetic atomic effects -- called *exchange forces* -- cause the alignment of atomic currents.



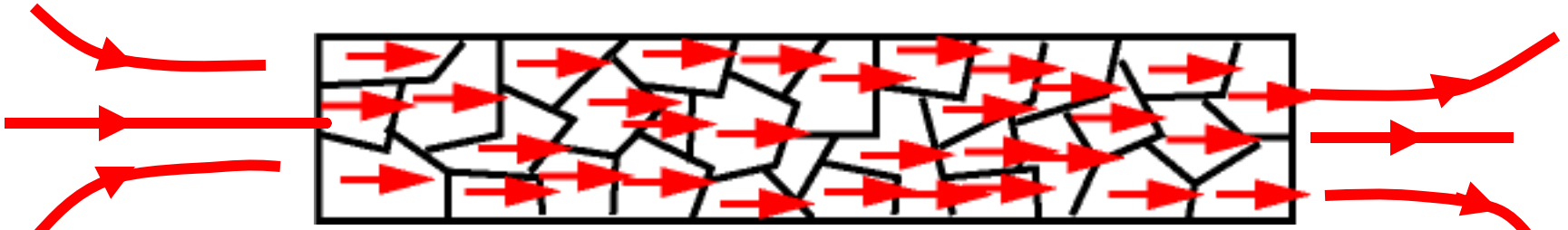
The magnetic properties of iron (and other ferromagnetic materials).

- **Non-magnetized**

→ domains are random

- **Magnetized**

→ domains are aligned

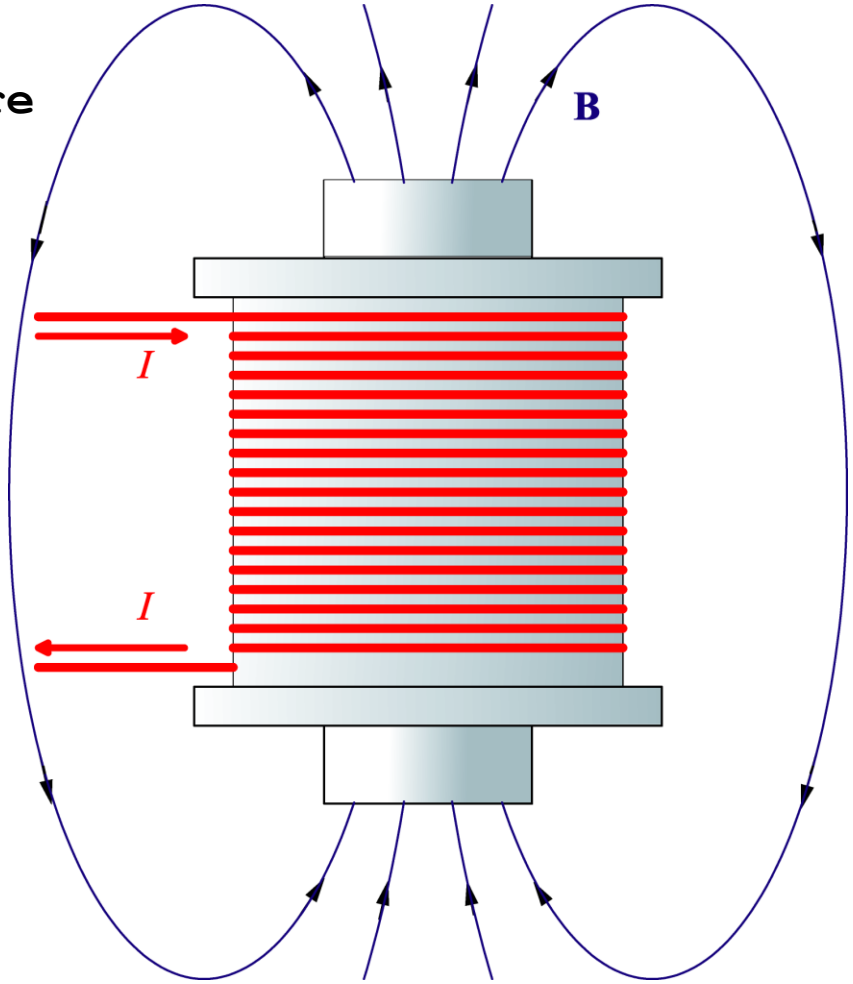


B, south pole

B, north pole

Electromagnets …

… a coil of current carrying wire wrapped around an iron core; a solenoid.



Applications:

- electric motors
- relay switches
- auto graveyard

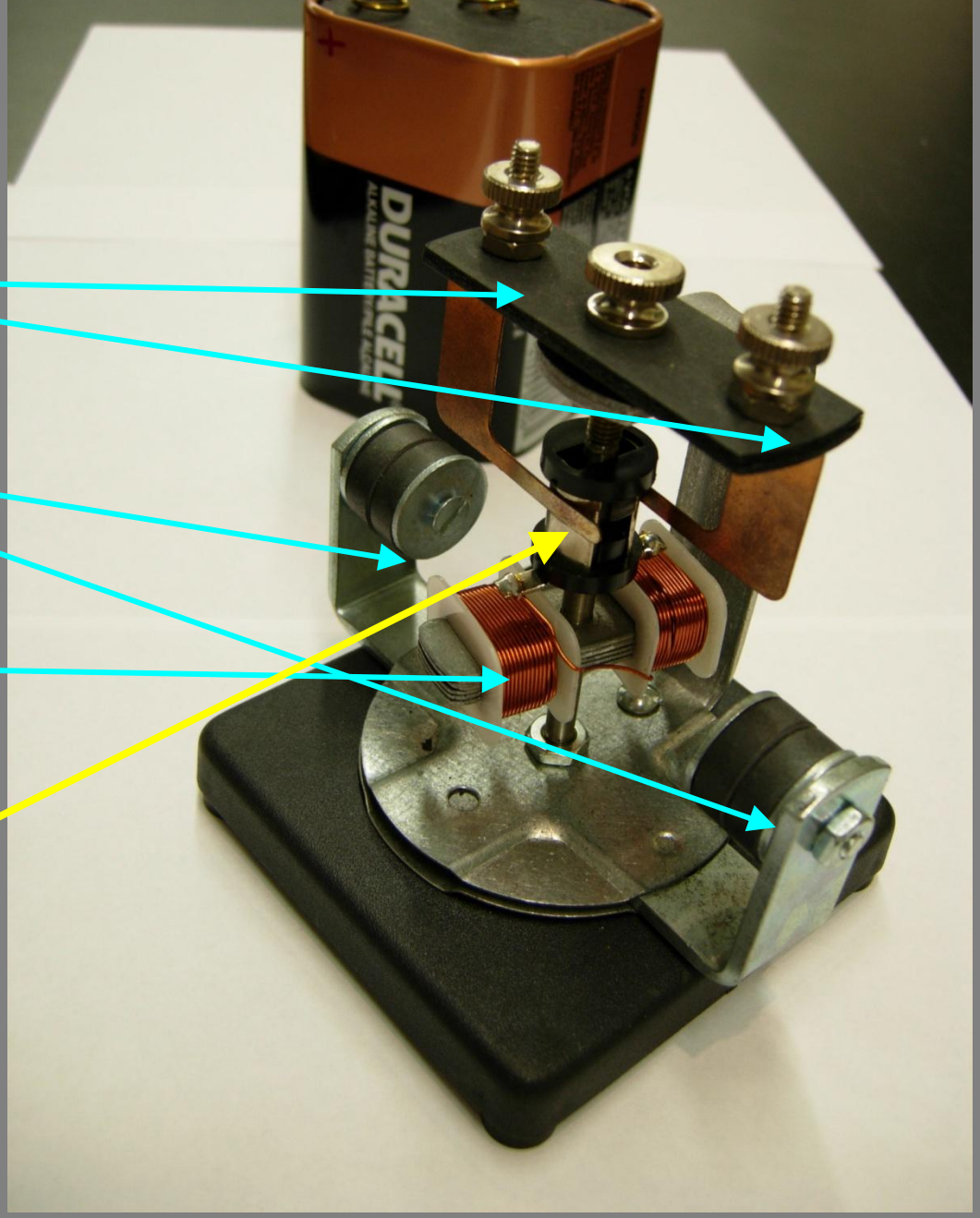
Model DC electric motor

Terminals

Magnets

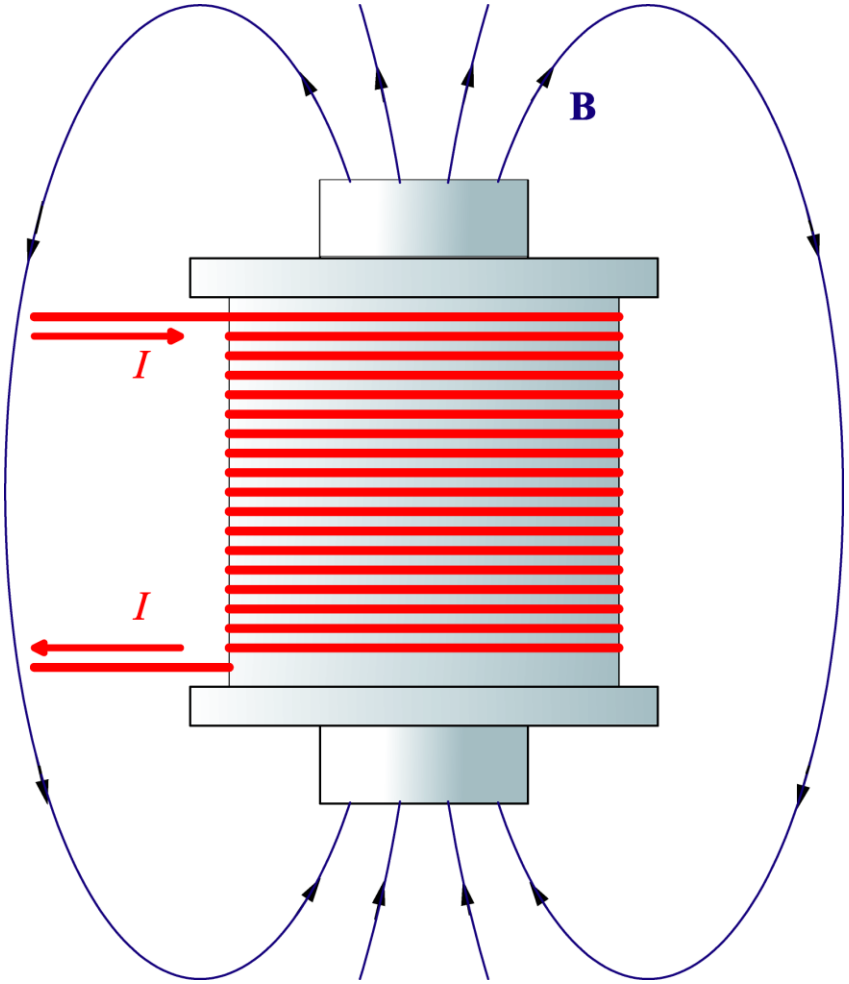
Rotor – copper coils and iron core

Commutator w/ sliding contacts



Electromagnets …

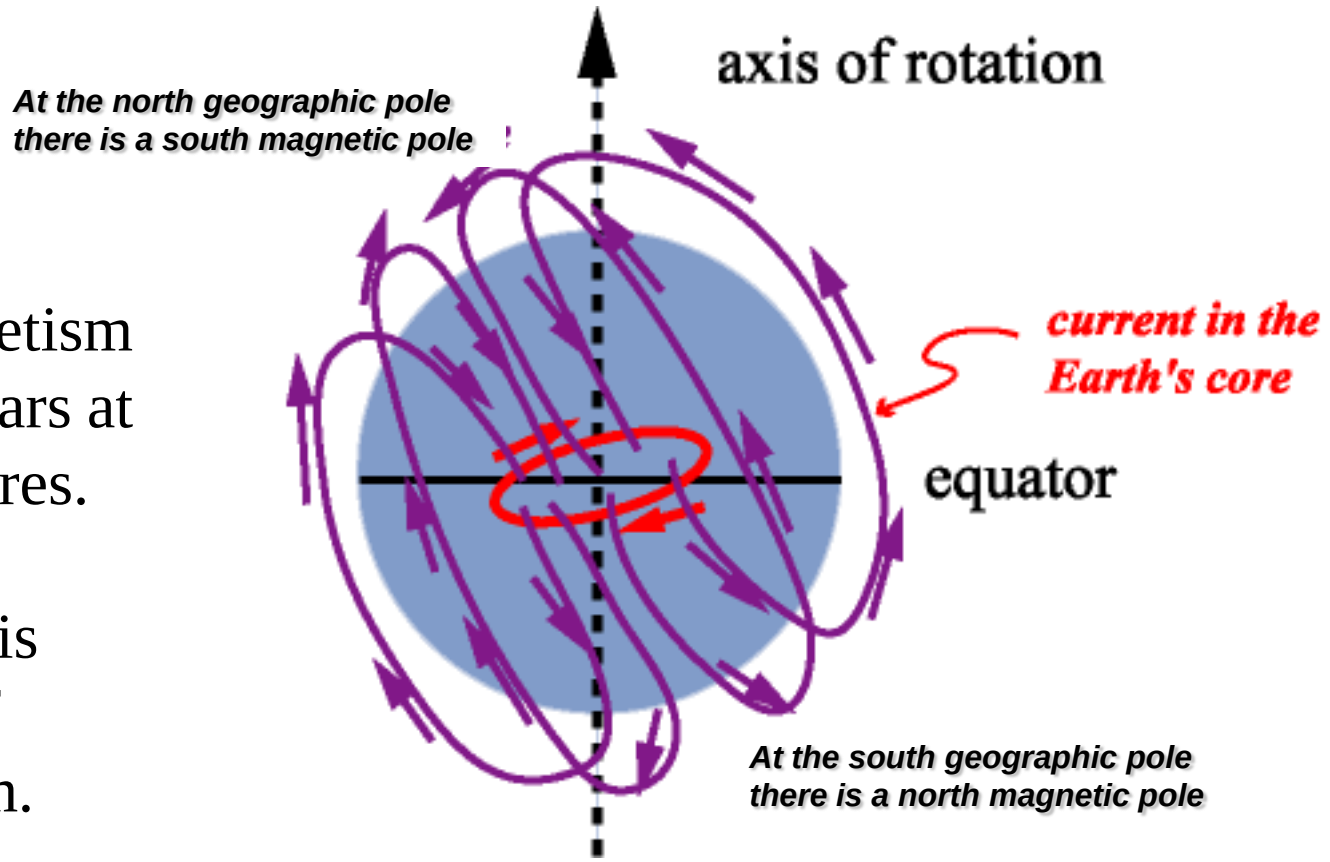
- The current I creates a magnetic field.
- The magnetic field magnetizes the iron core; i.e., the magnetic domains become aligned.
- The magnetized iron has a very strong magnetic field.
- If the iron is "soft" then the magnetization collapses when the current is turned off (I=0).



Applications:

- electric motors
- relay switches
- auto graveyard

The magnetic field of the Earth

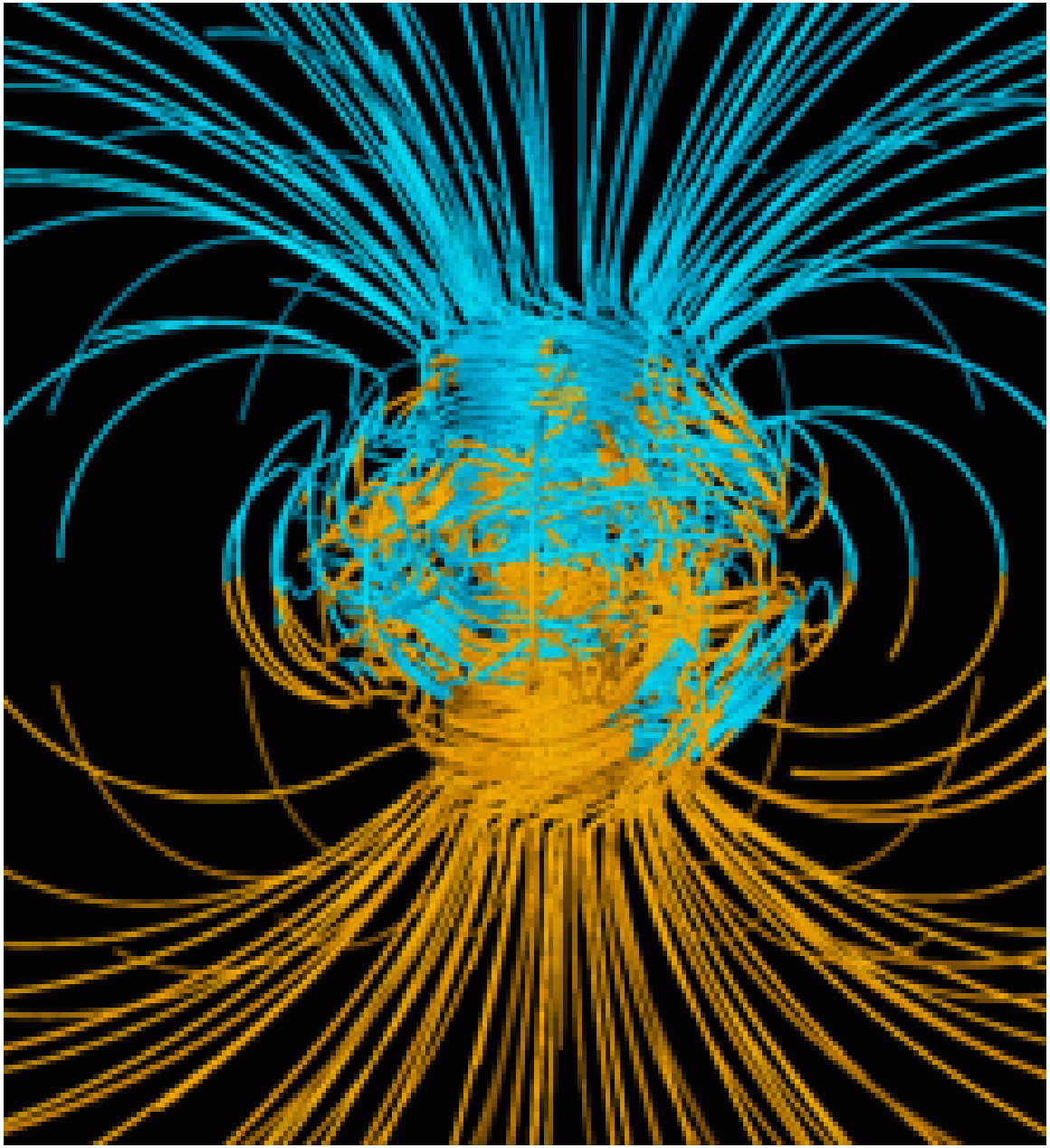


The ferromagnetism of iron disappears at high temperatures. The Earth's magnetic field is not an effect of ferromagnetism.

William Gilbert (1600) :

Magnus magnes ipse est globus terrestris.

computer
simulation



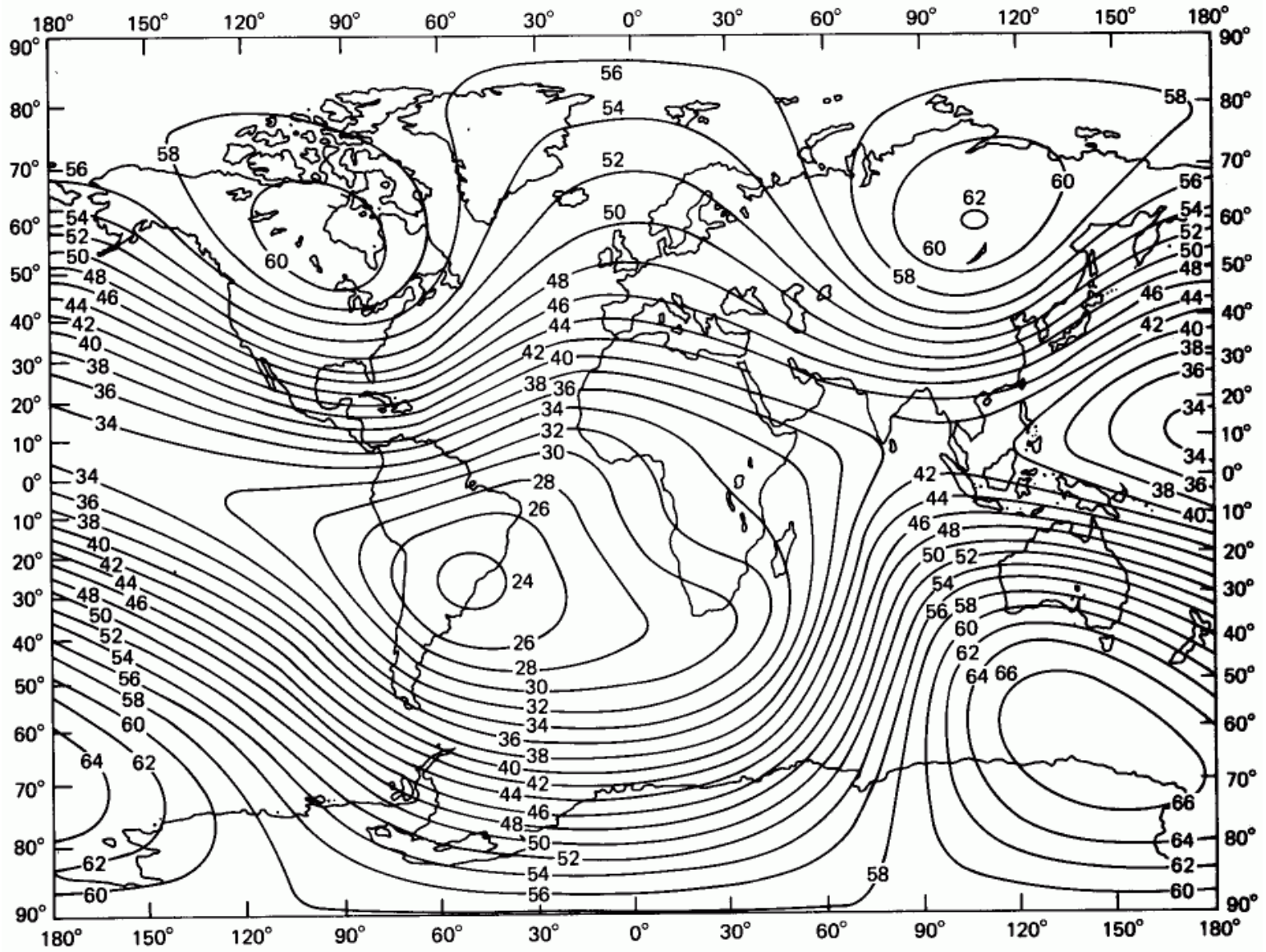


Figure 1-18 Present-day magnetic field of the earth. (*a*) Magnitude, μT.

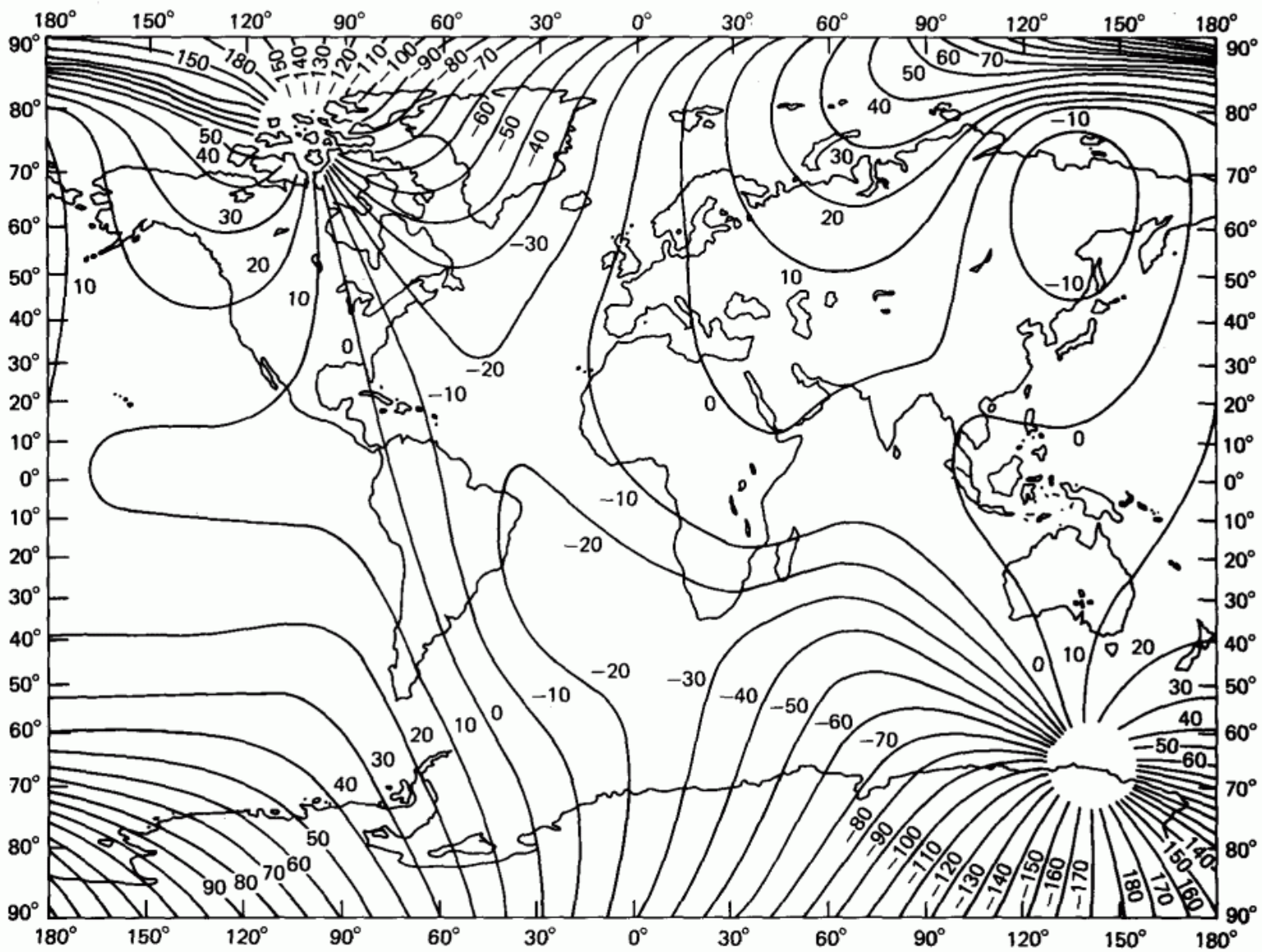


Figure 1-18 Present-day magnetic field of the earth. (*b*) Declination, deg.

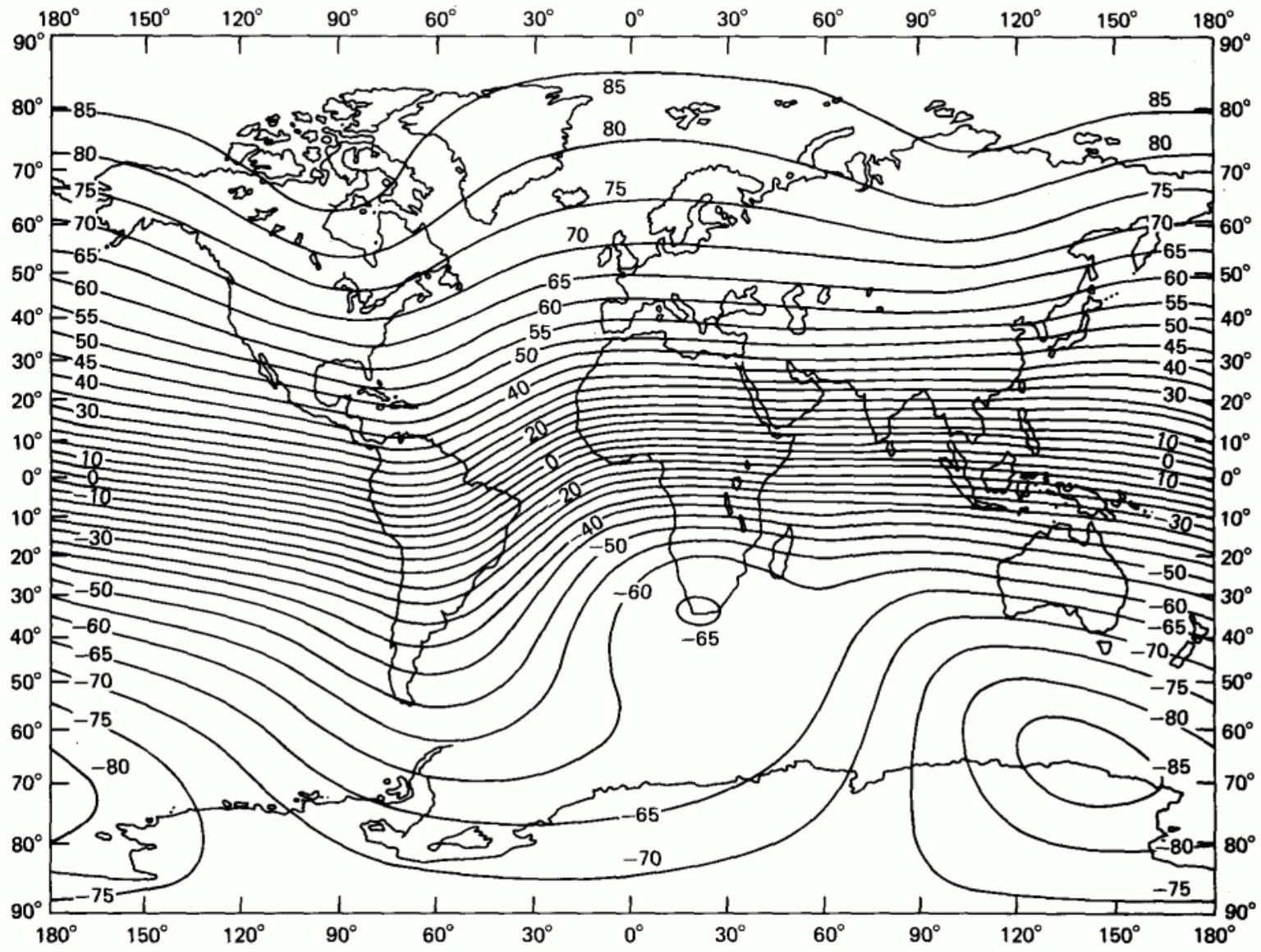


Figure 1-18 Present-day magnetic field of the earth. (*c*) Inclination, deg.