Magnetism

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

II. Magnetic Force on Current
 - parallel currents, motors

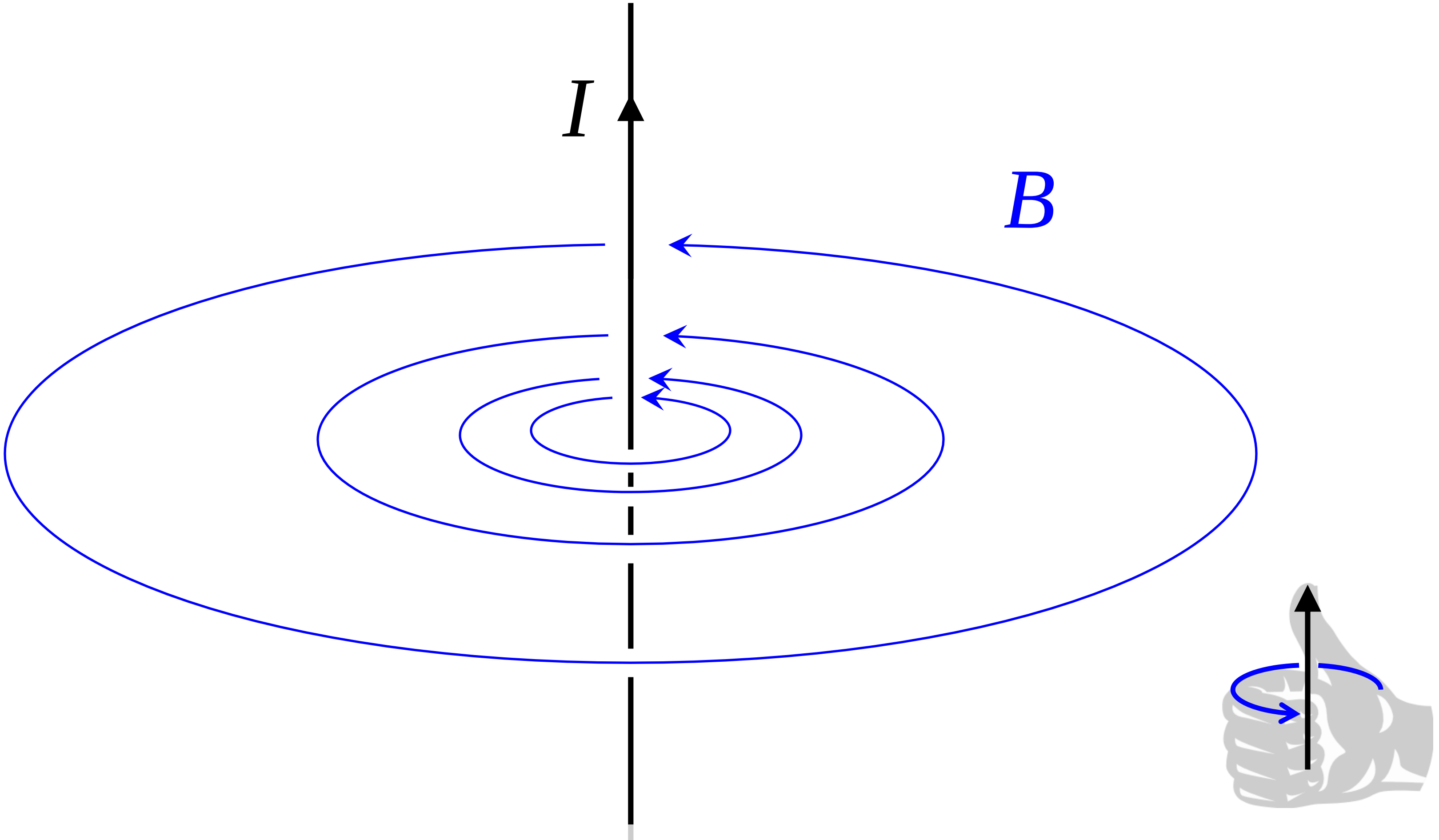
III. Sources of Magnetic Fields
 - Ampere's Law
 - solenoids

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

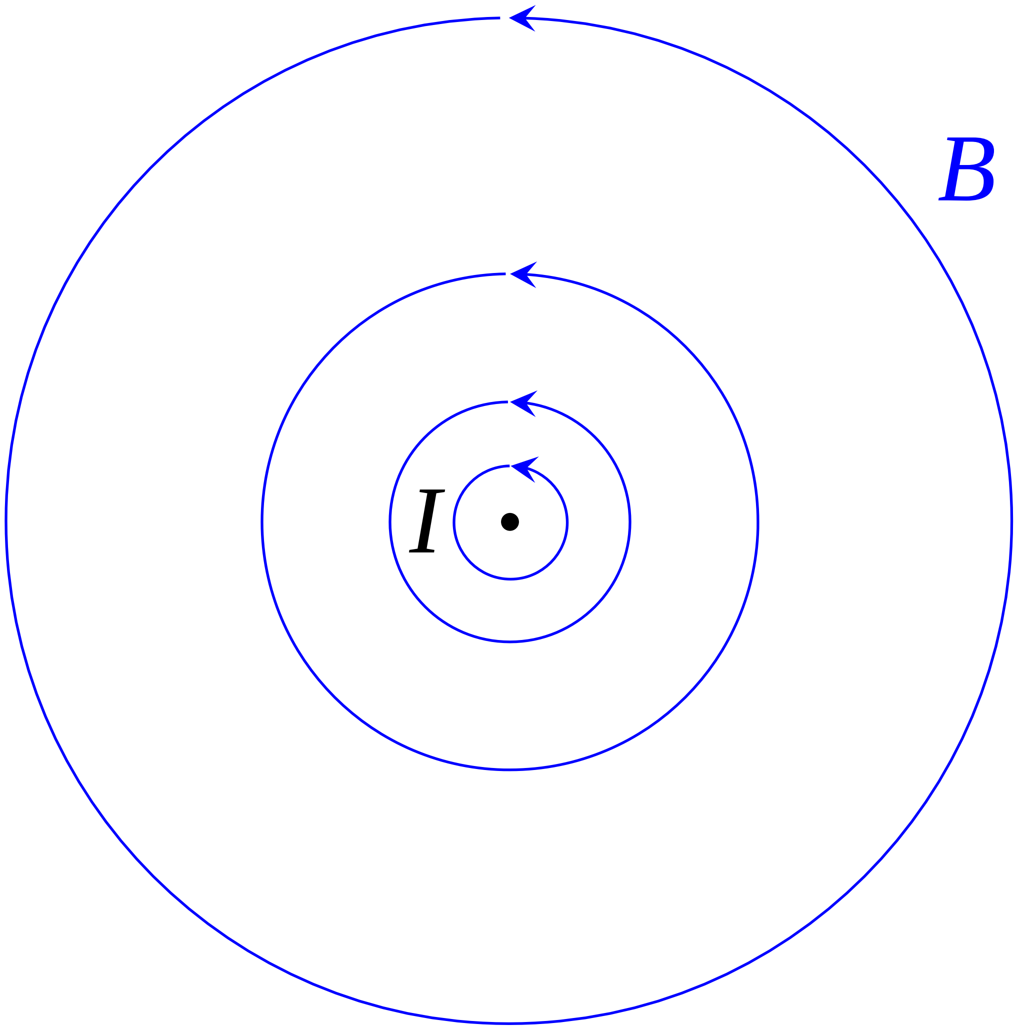
	The student will be able to:	HW:
1	Define and illustrate the basic properties of magnetic fields and permanent magnets: field lines, north and south poles, magnetic compasses, Earth's magnetic field.	✓ 1 – 4
2	Solve problems relating magnetic force to the motion of a charged particle through a magnetic field, such as that found in a mass spectrometer.	✓ 5 – 11
	Solve problems involving forces on a current carrying wire in a	✓

	The student will be able to:	HW:
4	State and apply relation between magnetic field and position for a long current carrying wire and solve related problems.	19 – 25

6	State and apply Faraday's Law and Lenz's Law and solve problems involving induced emf and magnetic flux.	31 – 38

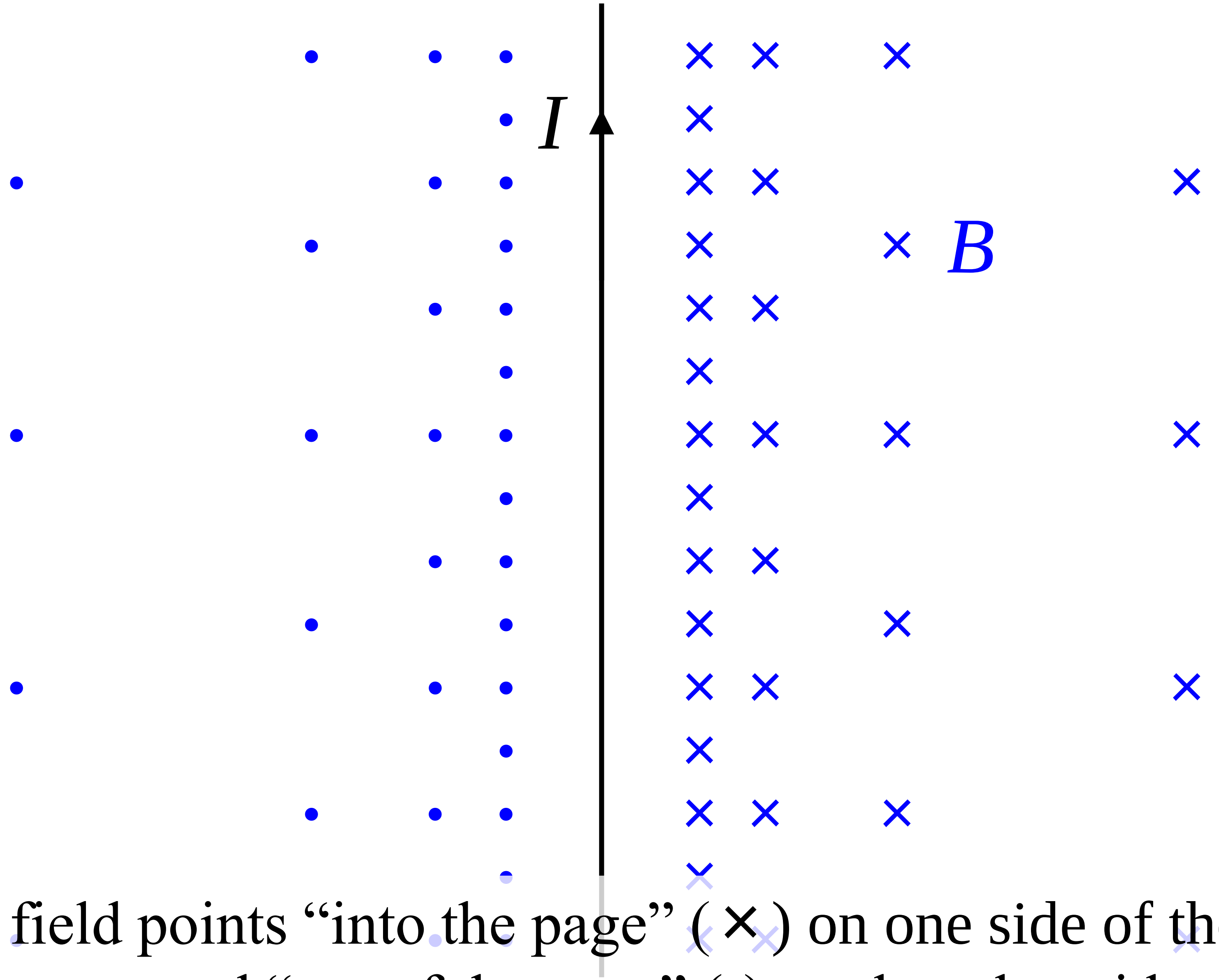


The magnetic field around a long straight current consists of concentric circles, seen here at an oblique angle. The direction of the field is given by a right hand rule: thumb in direction of current, fingers curl and point in direction of the field.



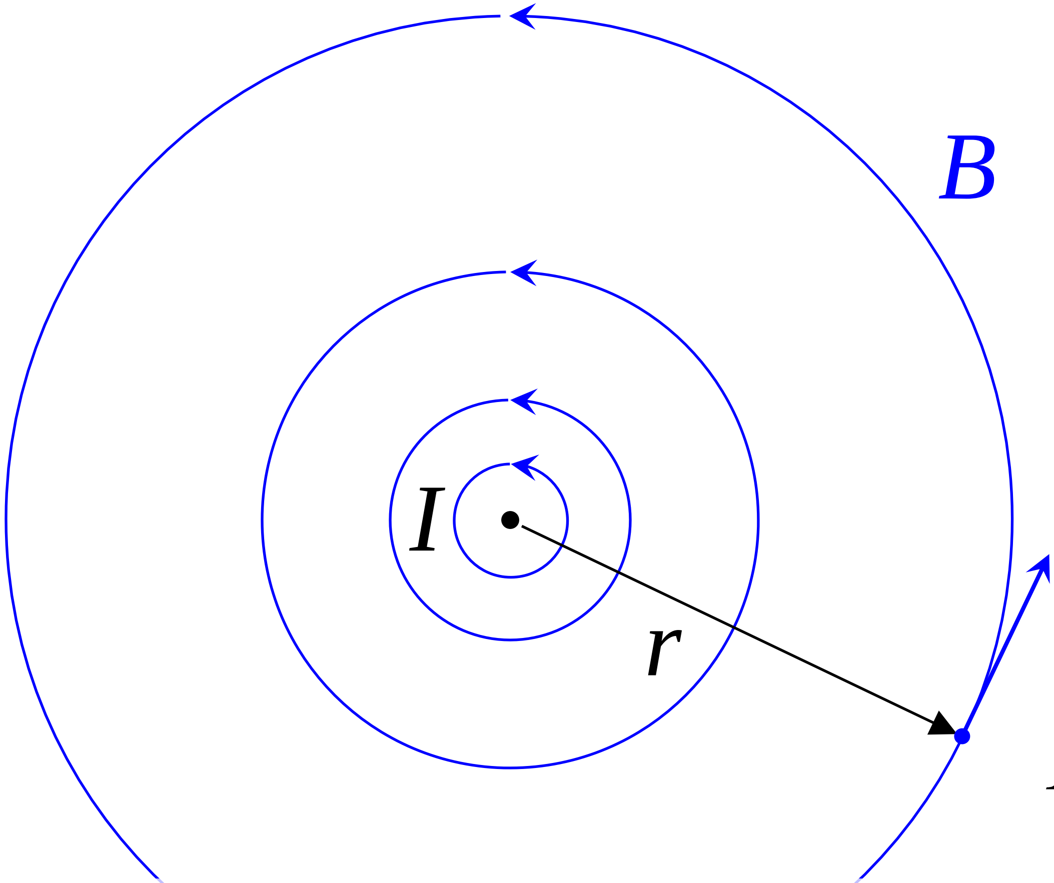
Same field seen "from above" such that the long straight current is "out of the page" – directly toward the eye.

A view of a plane that *contains* the long straight current…



… field points "into the page" (×) on one side of the current and "out of the page" (•) on the other side.

Magnetic Field of “infinite” Linear Current



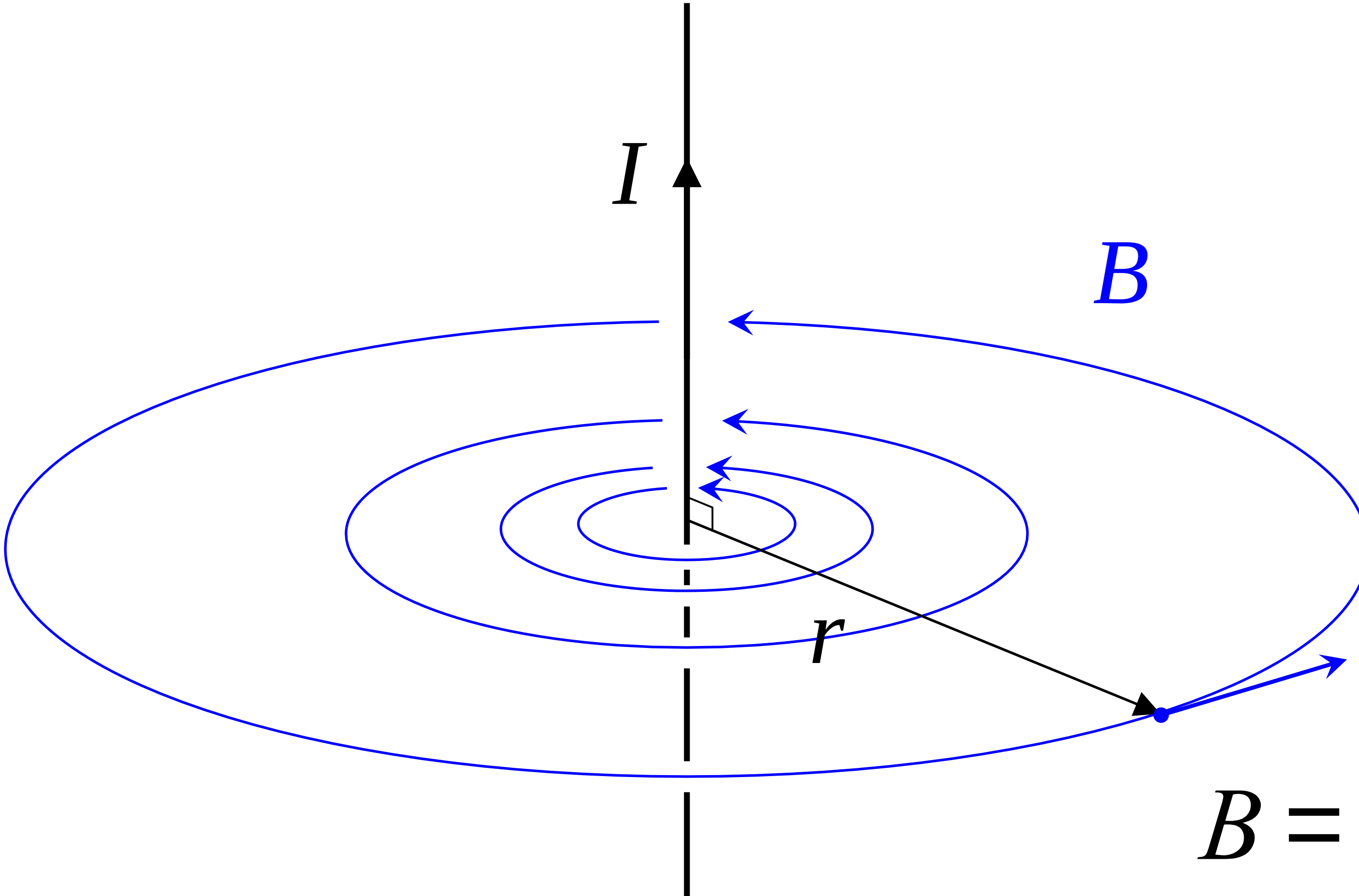
$$B = \frac{\mu_0 I}{2\pi r}$$

B = magnetic field strength

I = current (source of *B*)

r = perpendicular distance from *I*

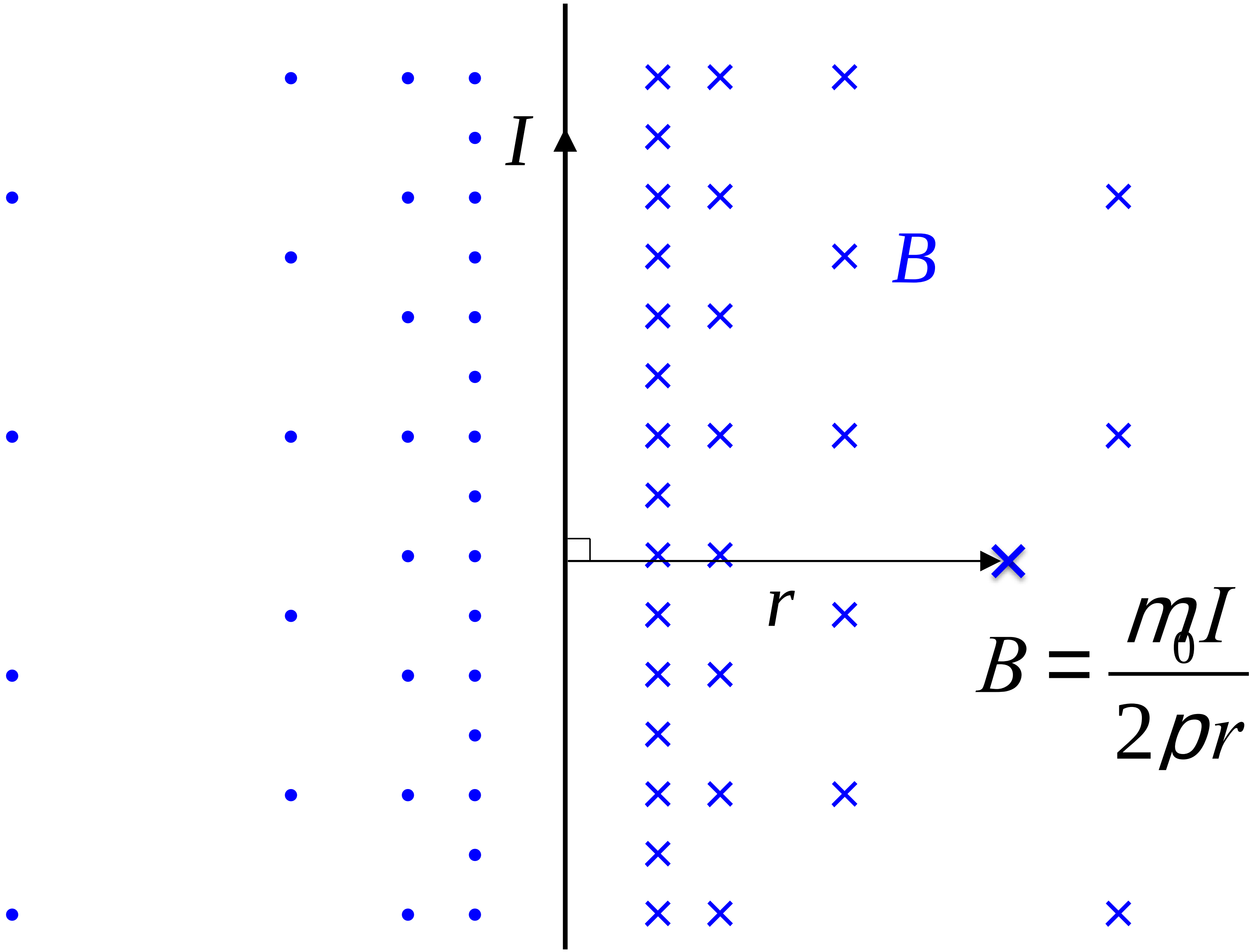
μ_0 = permeability constant



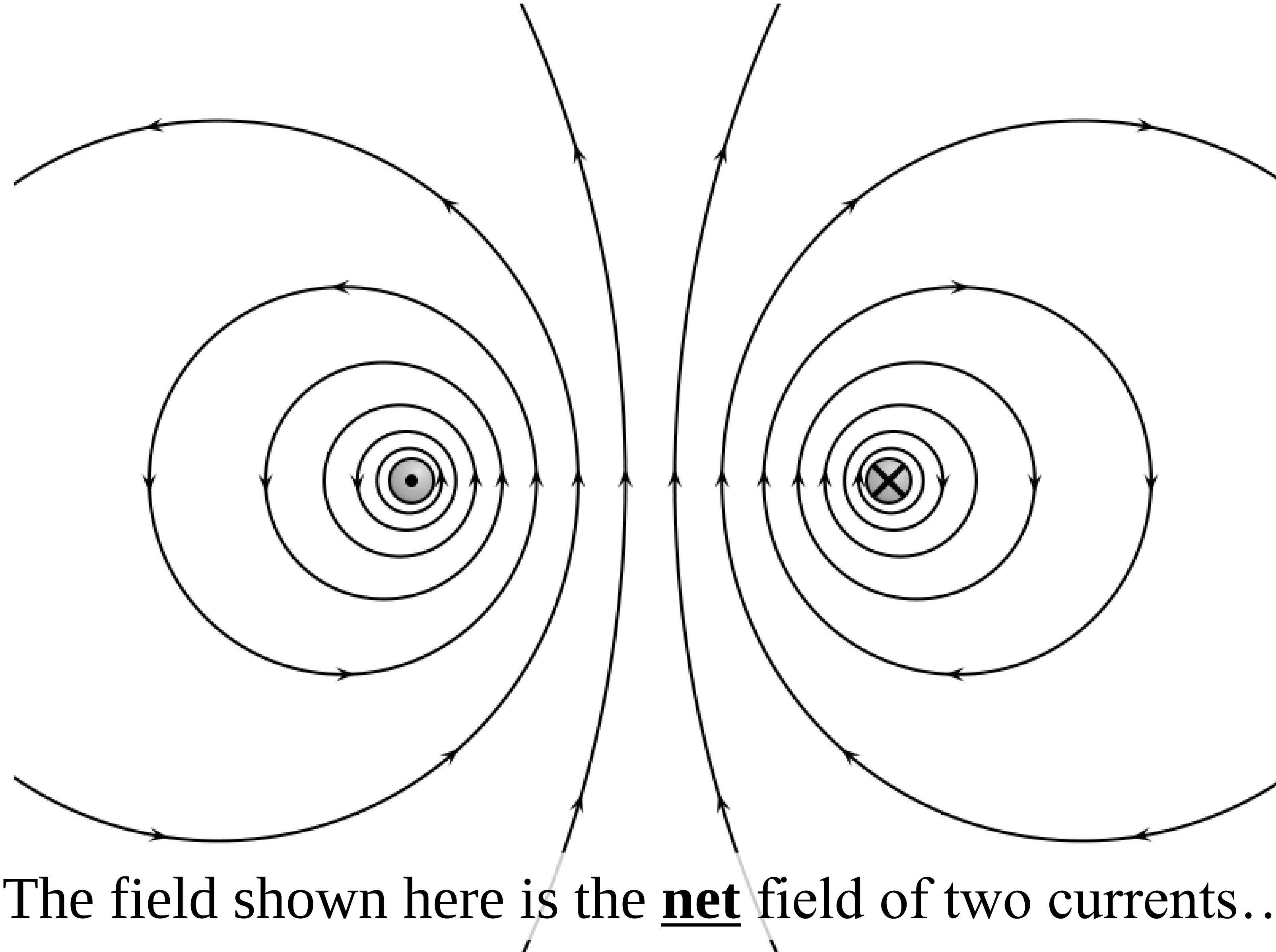
$$B = \frac{\mu_0 I}{2\pi r}$$

$$\mu_0 = 4\pi \times 10^{-7}\ \text{N/A}^2$$

The constant μ_0 in this equation is known as the magnetic permeability of free space – applies to a vacuum or essentially the same for air.


I
B
r
$B = \frac{m_0 I}{2pr}$

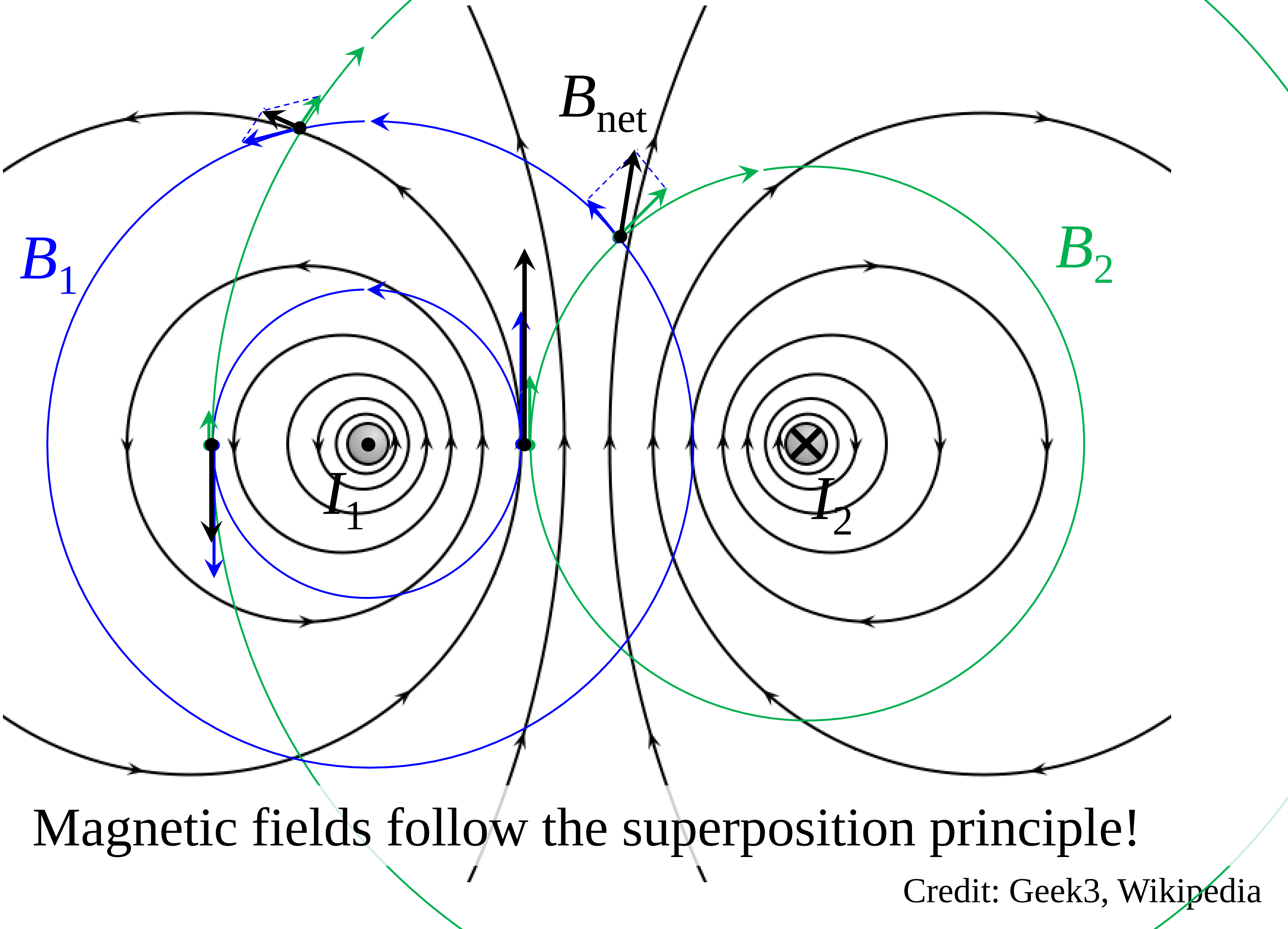
Magnetic Field – Antiparallel Currents



The field shown here is the **net** field of two currents…

Credit: Geek3, Wikipedia

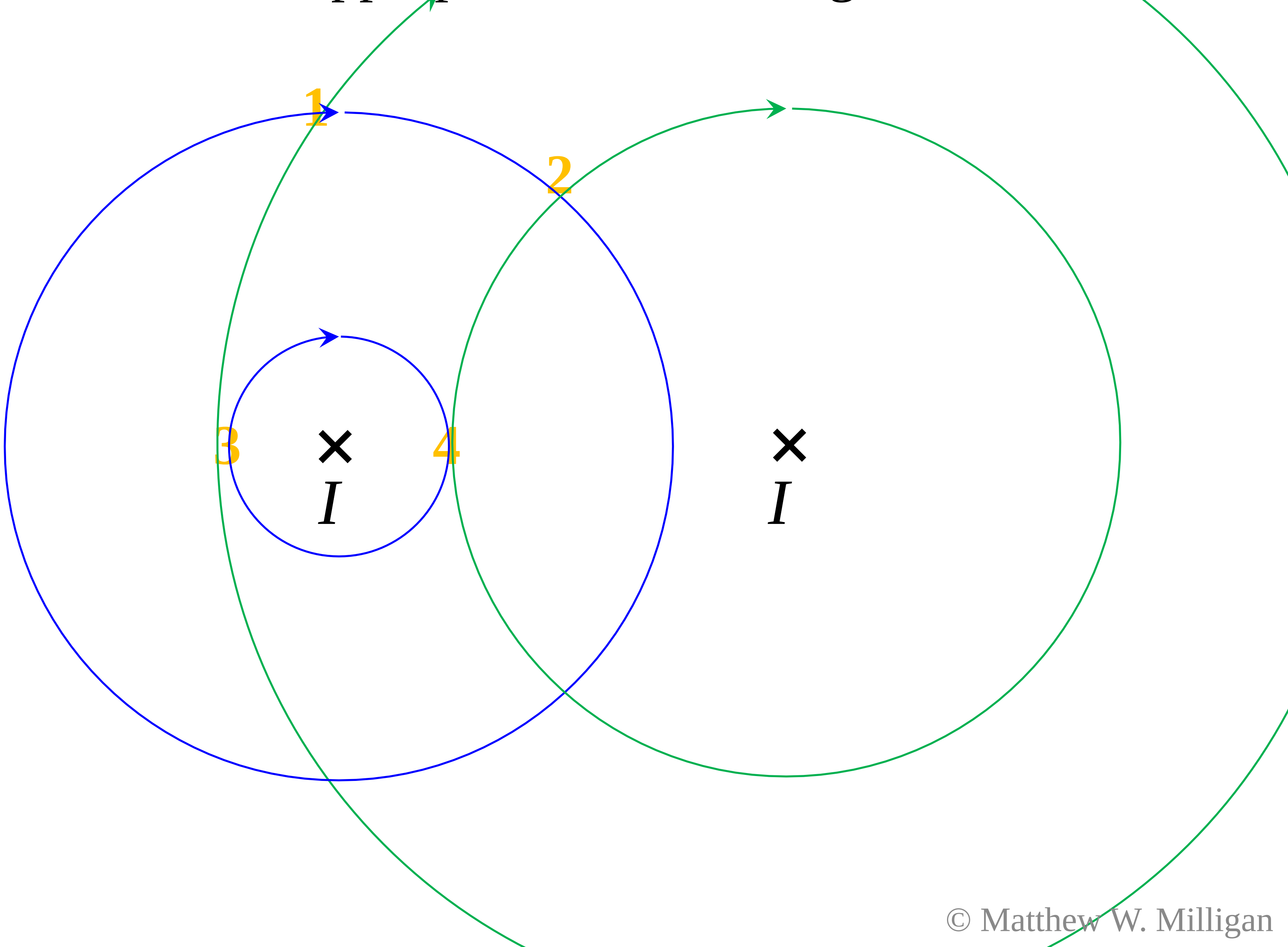
Magnetic Field – Antiparallel Currents

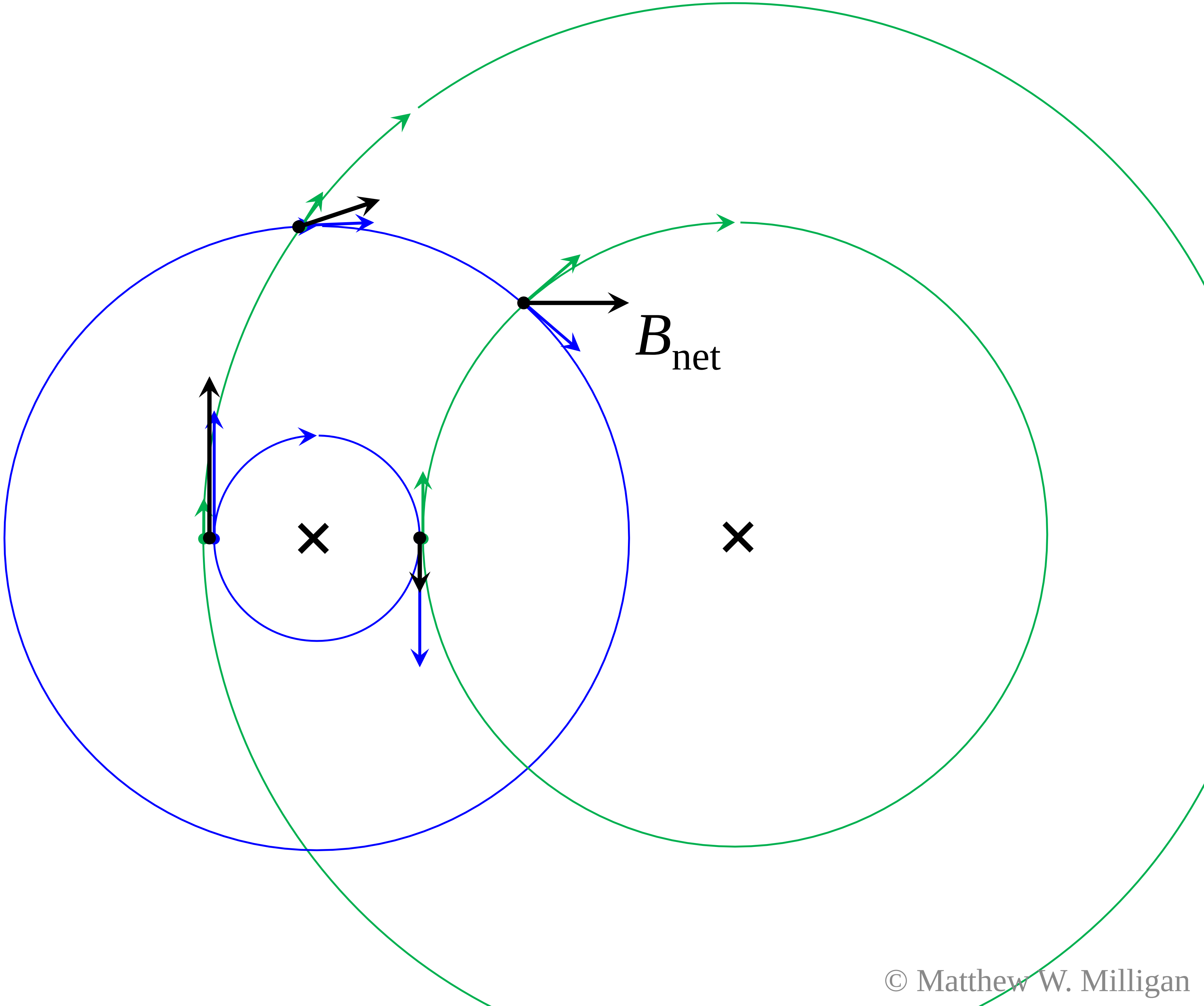


Magnetic fields follow the superposition principle!

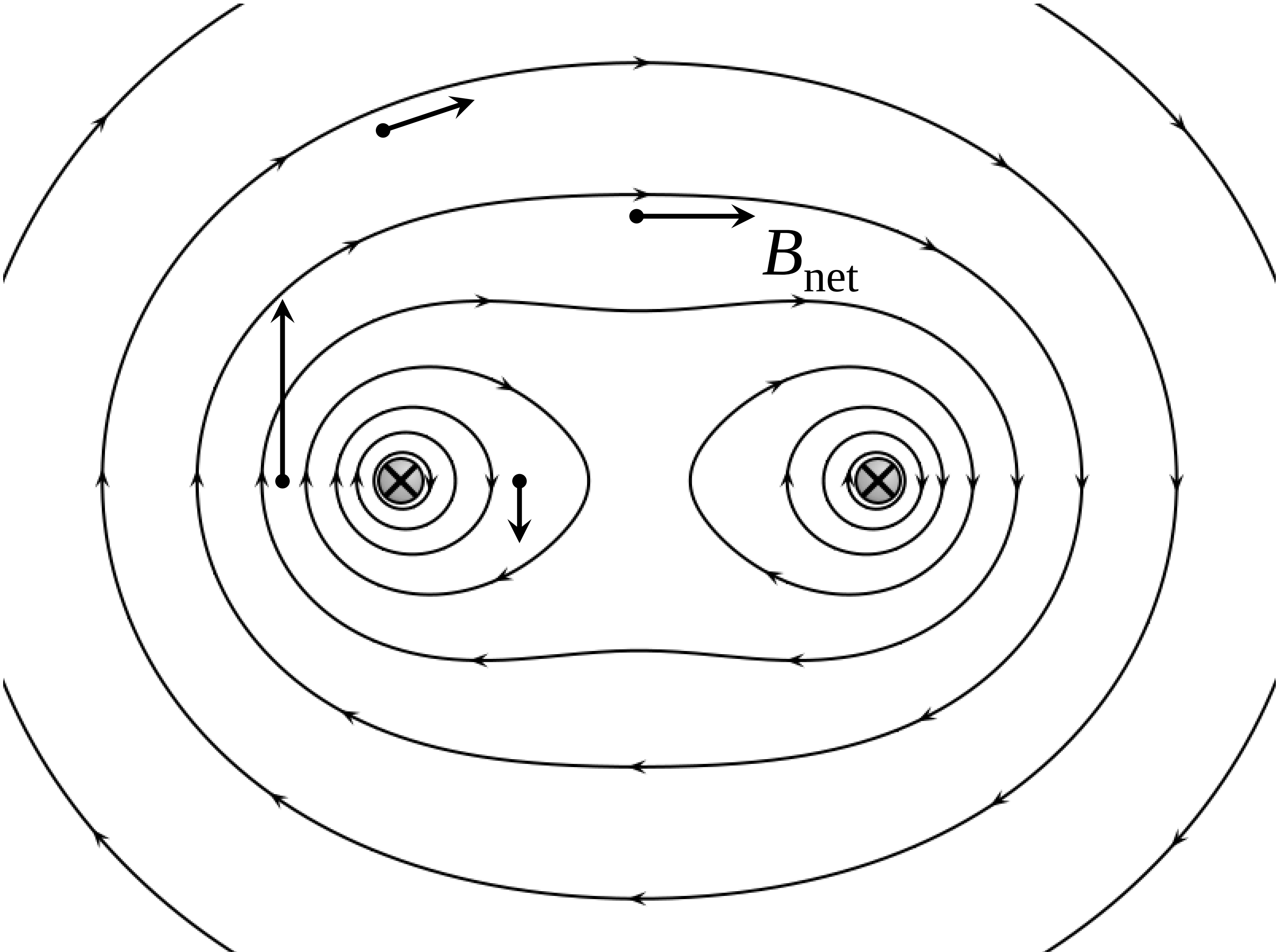
Credit: Geek3, Wikipedia

Draw a vector diagram illustrating superposition at each of four locations, with appropriate relative lengths of the arrows:




B_{net}

Magnetic Field – Parallel Currents



Credit: Geek3, Wikipedia

Ampere's Law – Simplified Version

Ampere's Law describes the magnetic field in the vicinity of *any* current (not just an infinite straight one).

$$\vec{B} \cdot \vec{\ell} = \mu_0 I$$

$$B_{||}\ell = B\ell_{||} = \mu_0 I$$

B = magnetic field (<u>average</u> or <u>constant</u>)

I = current (source of B)

ℓ = length of path that goes around I

Ampere's Law – Simplified Version

In certain *special* cases this law may be used to solve for an unknown magnetic field. However, it is necessary to analyze a path surrounding a certain current along which the field is either constant <u>and</u> parallel to the path, perpendicular to the path, and/or nonexistent.

$$\vec{B} \cdot \vec{\ell} = \mu_0 I$$

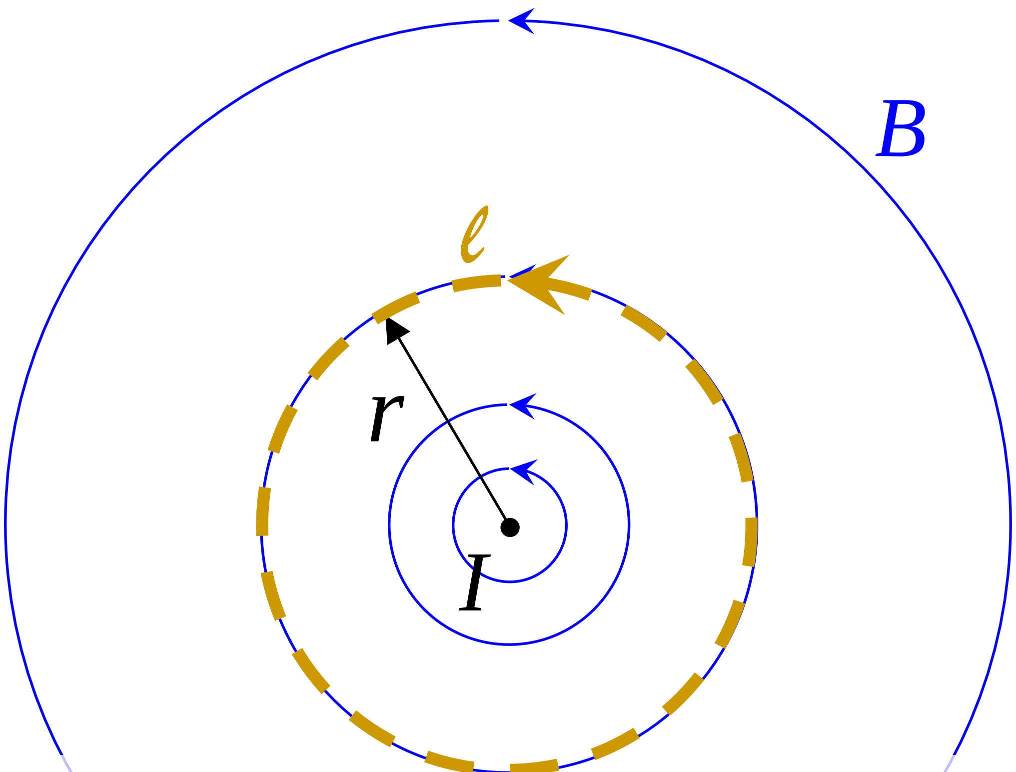
$$B_{||}\ell = B\ell_{||} = \mu_0 I$$

B = magnetic field (average or constant)

I = current (source of B)

ℓ = length of path that goes around I

Ampere's Law Example



$$\vec{B} \cdot \vec{\ell} = \mu_0 I$$

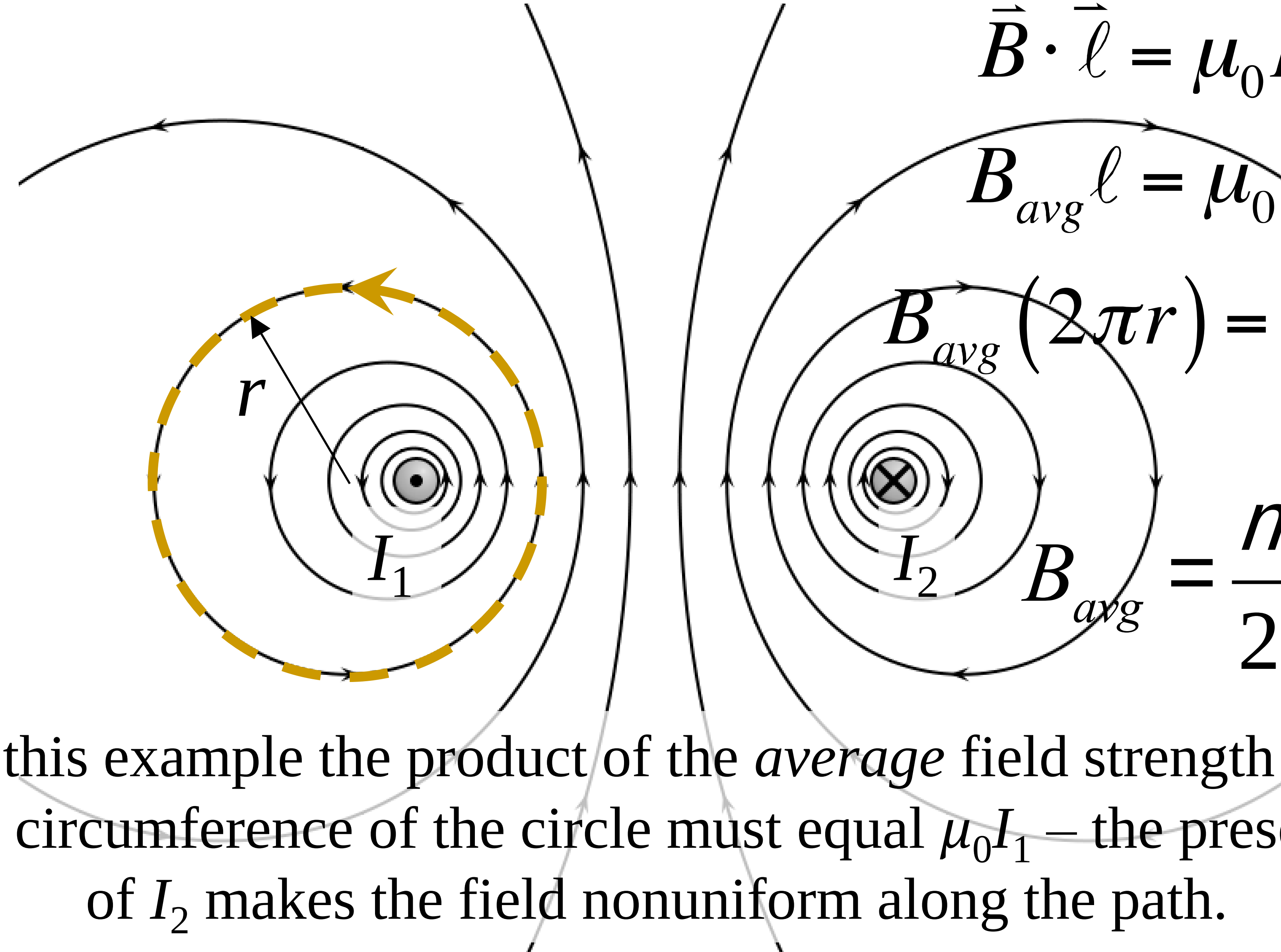
$$B\ell = \mu_0 I$$

$$B(2\pi r) = \mu_0 I$$

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

For a long, straight current in a wire, a circular path of radius *r* will be parallel to the field and the field will have constant magnitude along this path. By Ampere's Law the product of the field and the circumference of the circle must equal $\mu_0 I$.

Magnetic Field – Antiparallel Currents



$$\vec{B} \cdot \vec{\ell} = \mu_0 I_1$$

$$B_{avg} \ell = \mu_0 I_1$$

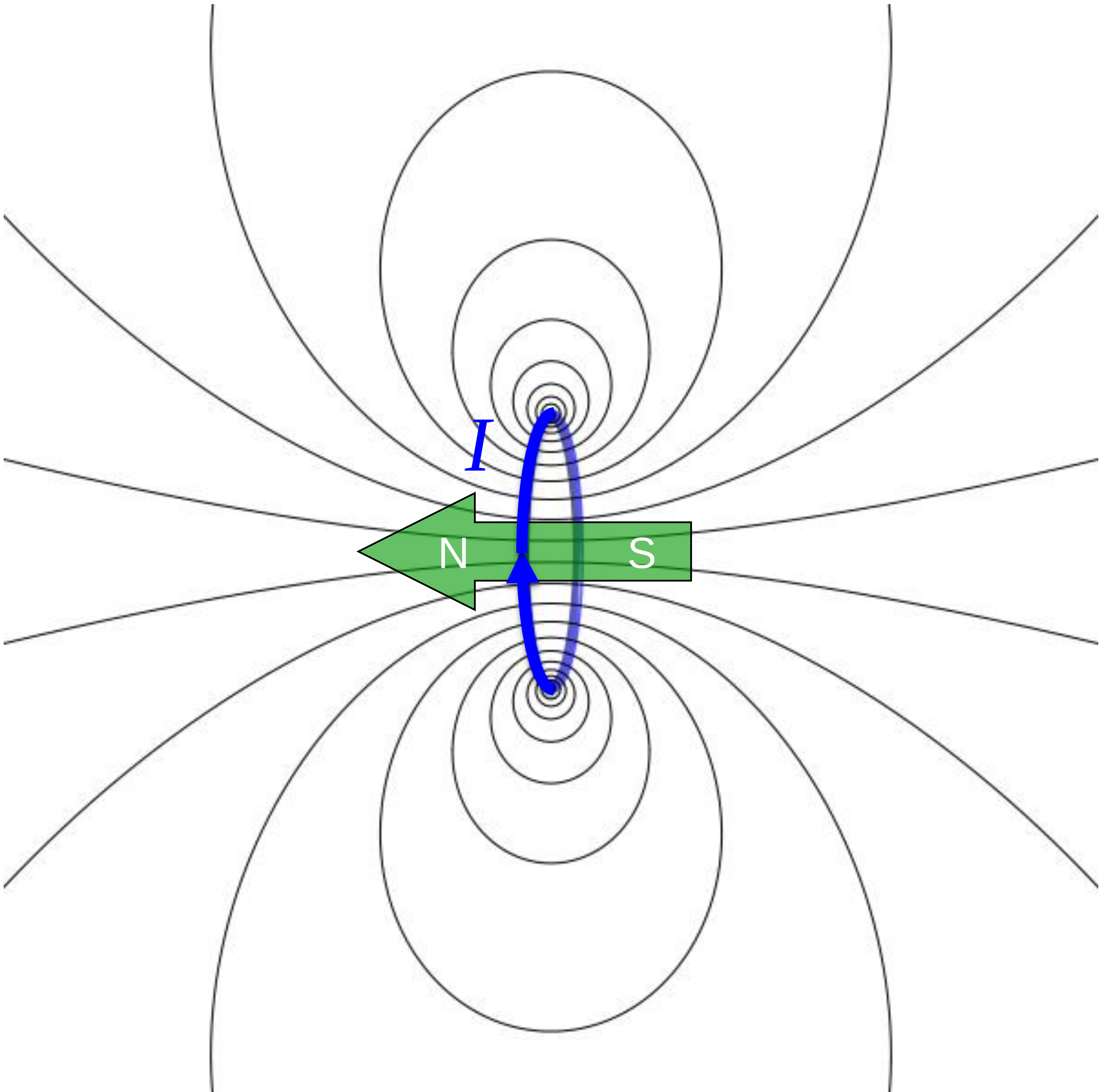
$$B_{avg}(2\pi r) = \mu_0 I_1$$

$$B_{avg} = \frac{m_0 I_1}{2pr}$$

In this example the product of the *average* field strength and the circumference of the circle must equal $\mu_0 I_1$ – the presence of I_2 makes the field nonuniform along the path.

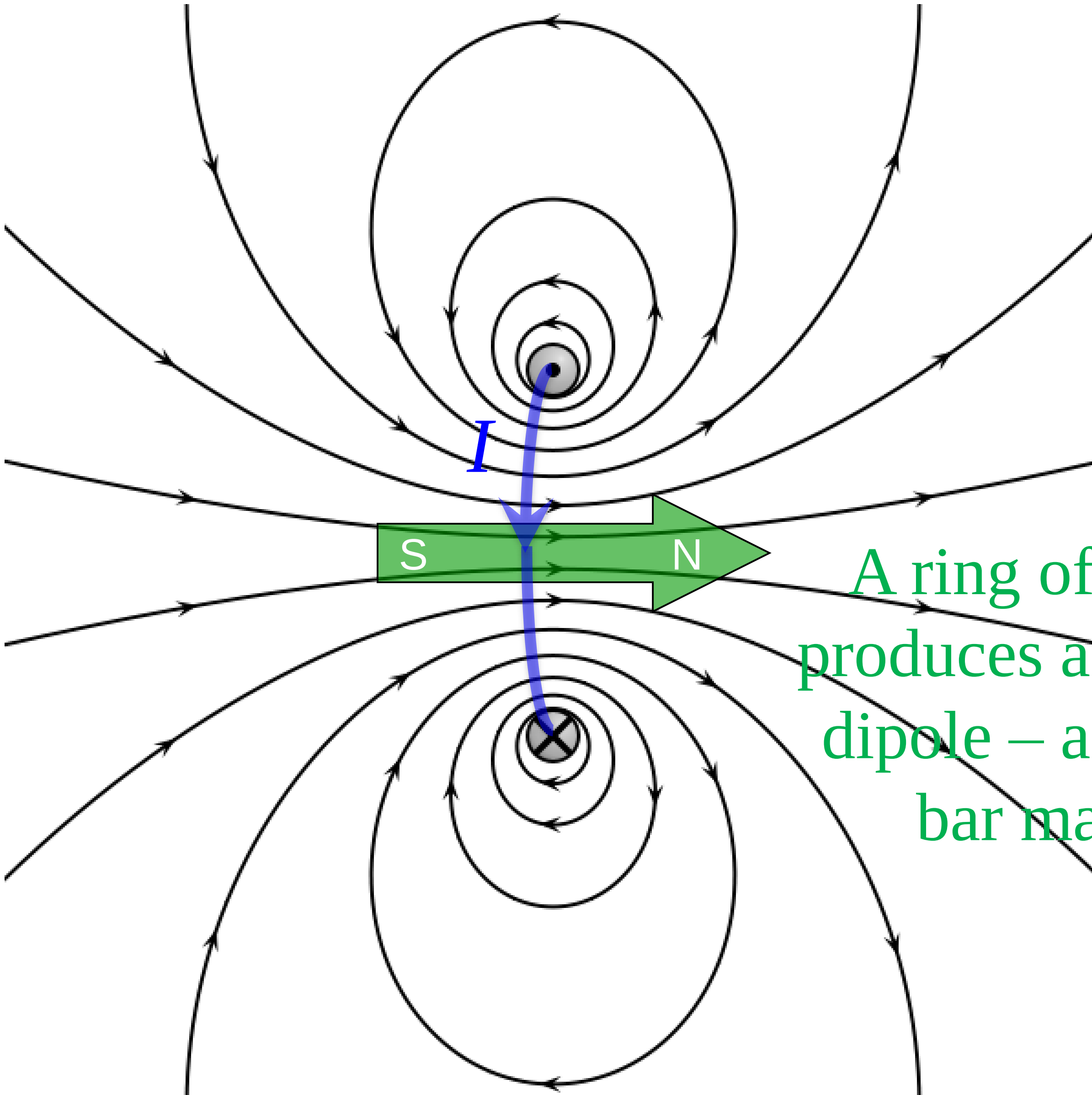
Credit: Geek3, Wikipedia

Magnetic Field – Ring of Current



Credit: Geek3, Wikipedia

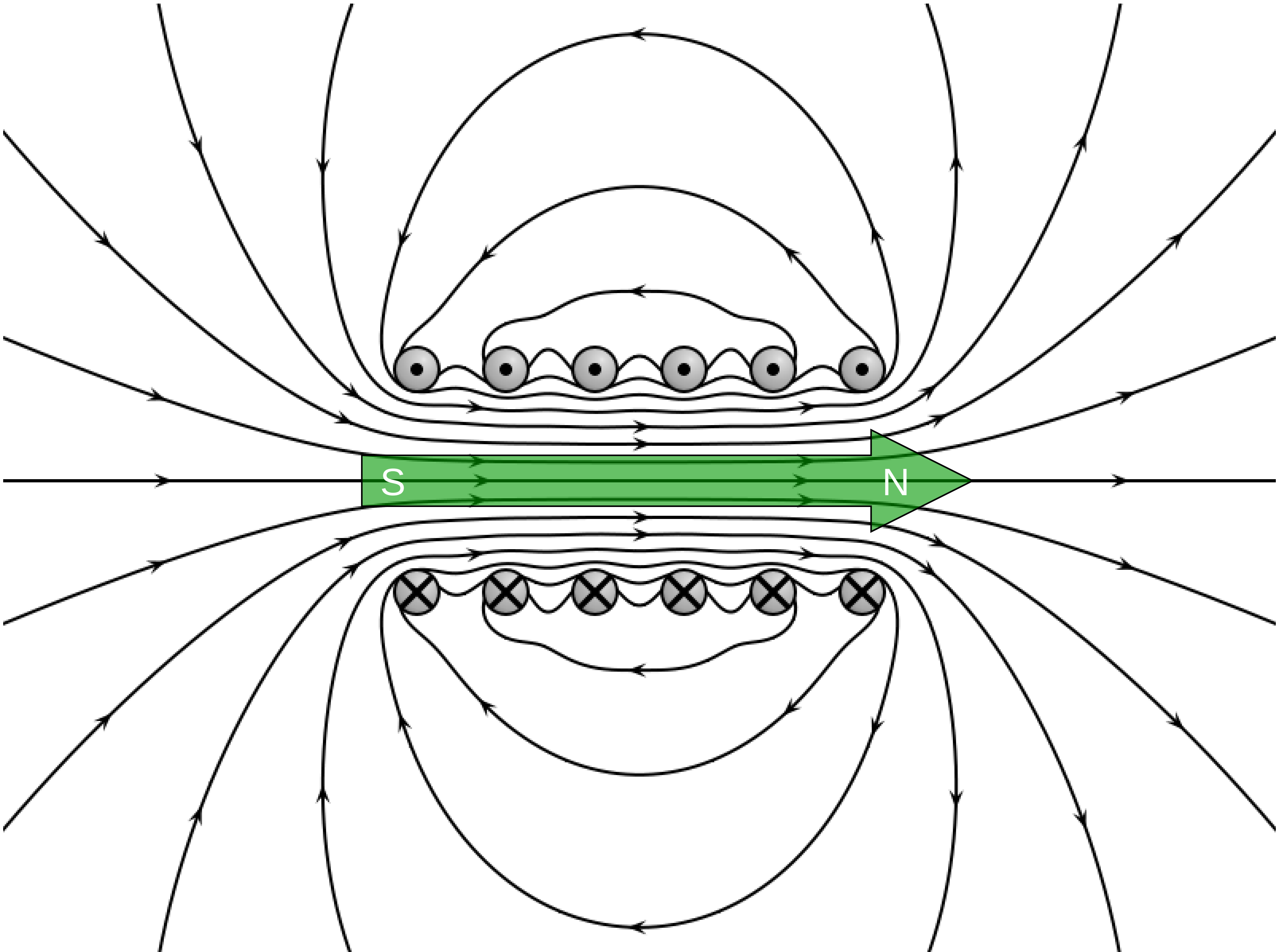
Magnetic Field – Ring of Current



A ring of current produces a magnetic dipole – acts like a bar magnet.

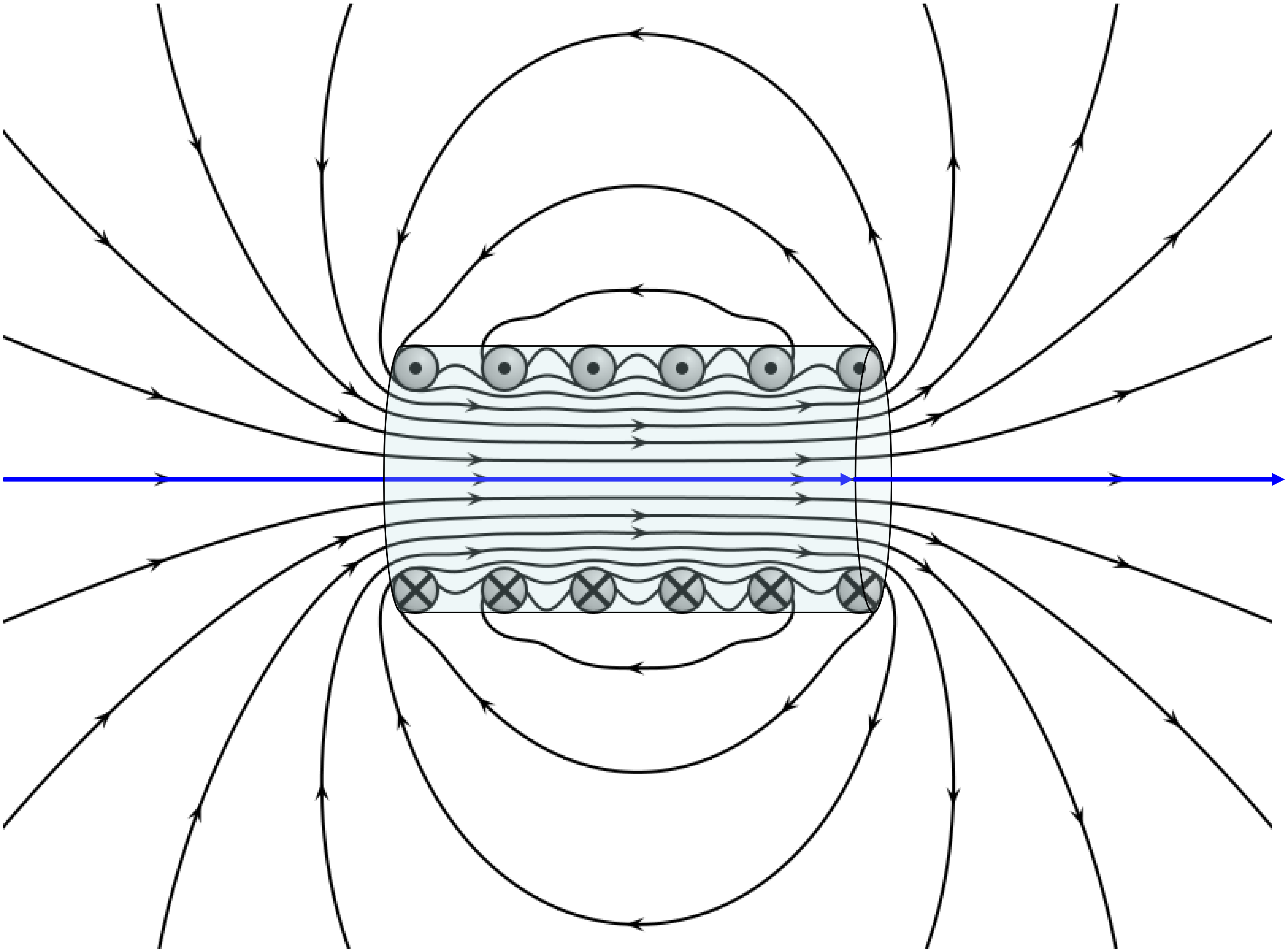
Credit: Geek3, Wikipedia

Magnetic Field – Solenoid



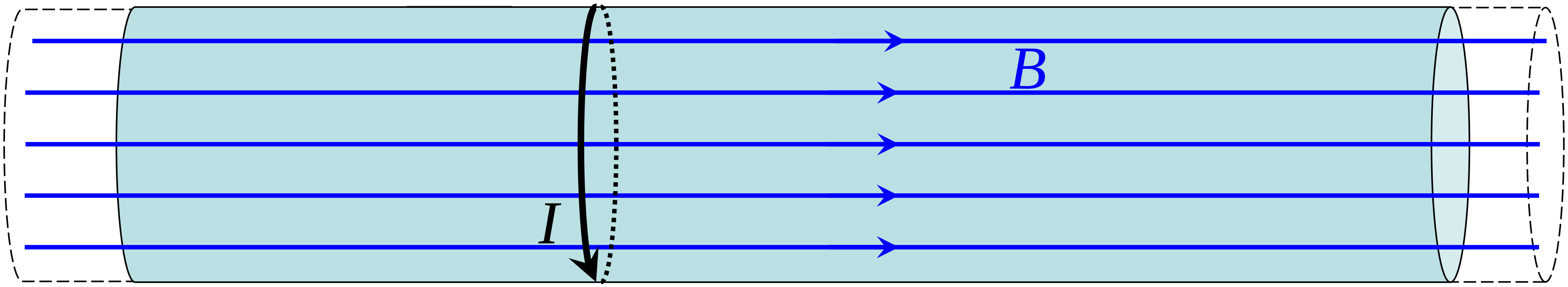
Credit: Geek3, Wikipedia

Magnetic Field – Solenoid



Credit: Geek3, Wikipedia

Magnetic Field – Ideal "Infinite" Solenoid



$$B = \mu_0 n I$$

or

$$B = \frac{\mu_0 N I}{L}$$

B = field *anywhere* inside (uniform)

n = number of turns per length

N = number of turns (or coils) of wire

L = length of cylinder

I = current