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
    Solenoids

	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 – 40

Magnetic Force on Charges

A moving charged particle will experience a force in a magnetic field:

$$\vec{F}_m = q\vec{v} \times \vec{B}$$

F = force on the particle
q = charge of the particle
v = velocity
B = magnetic field

Magnetic Force on Charges

A moving charged particle will experience a force in a magnetic field:

$$\left|\vec{\mathrm{F}}_m\right| = \left|qvB\sin\theta\right|$$

$$F_M = qv_{\wedge}B = qvB_{\wedge}$$

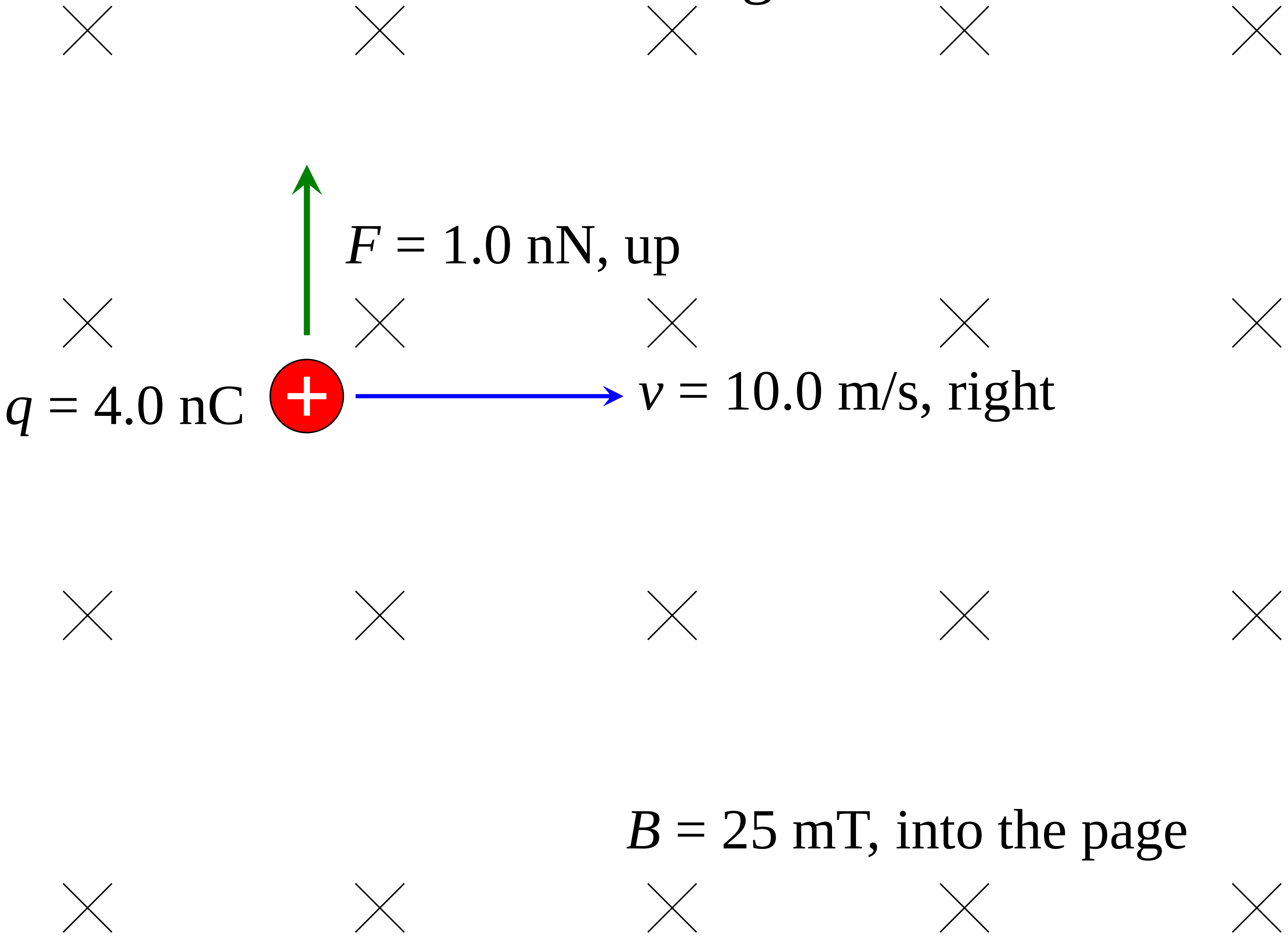
F = force on the particle

q = charge of the particle

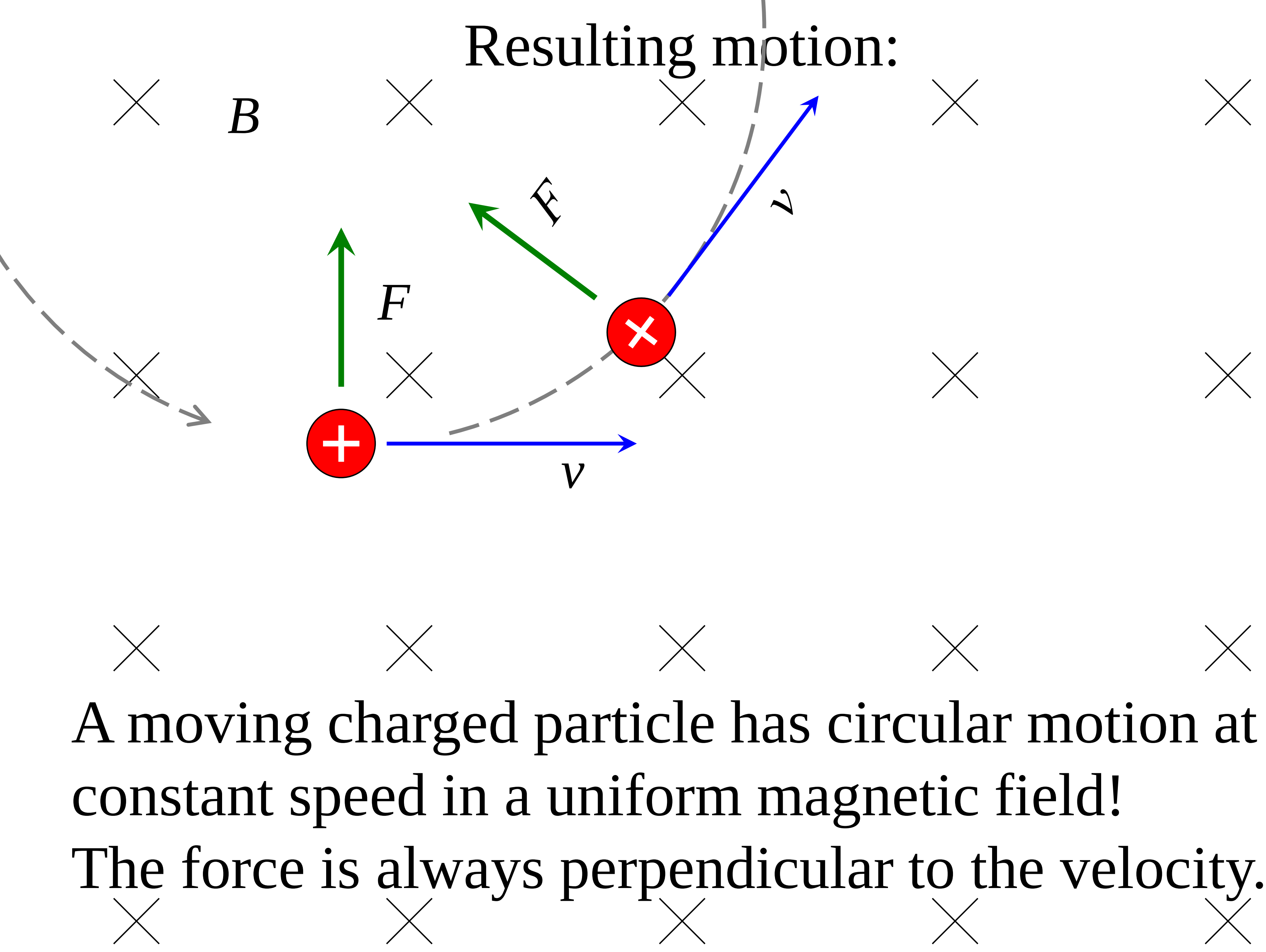
v = velocity

B = magnetic field

Determine the magnetic force:

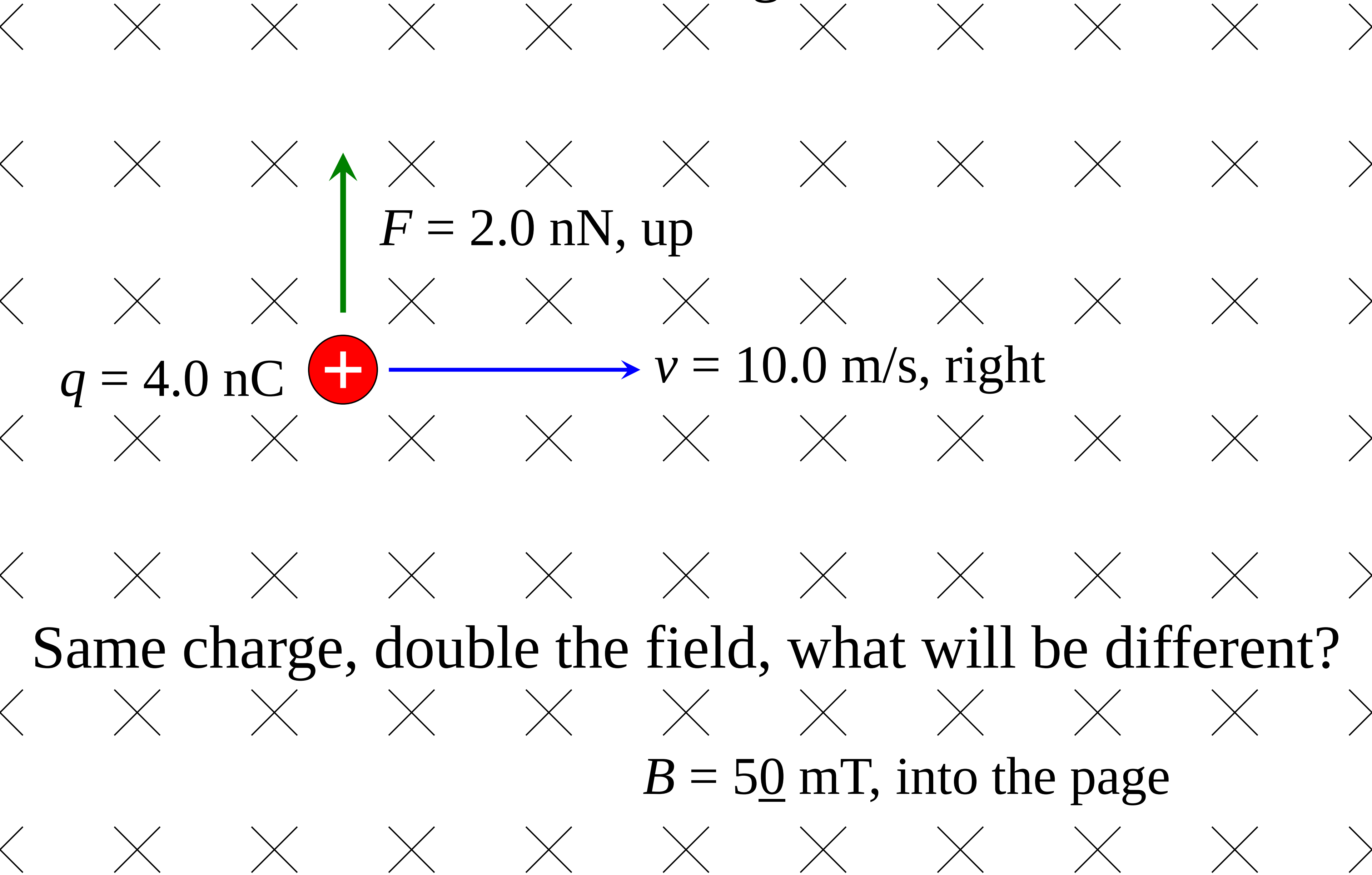


Resulting motion:



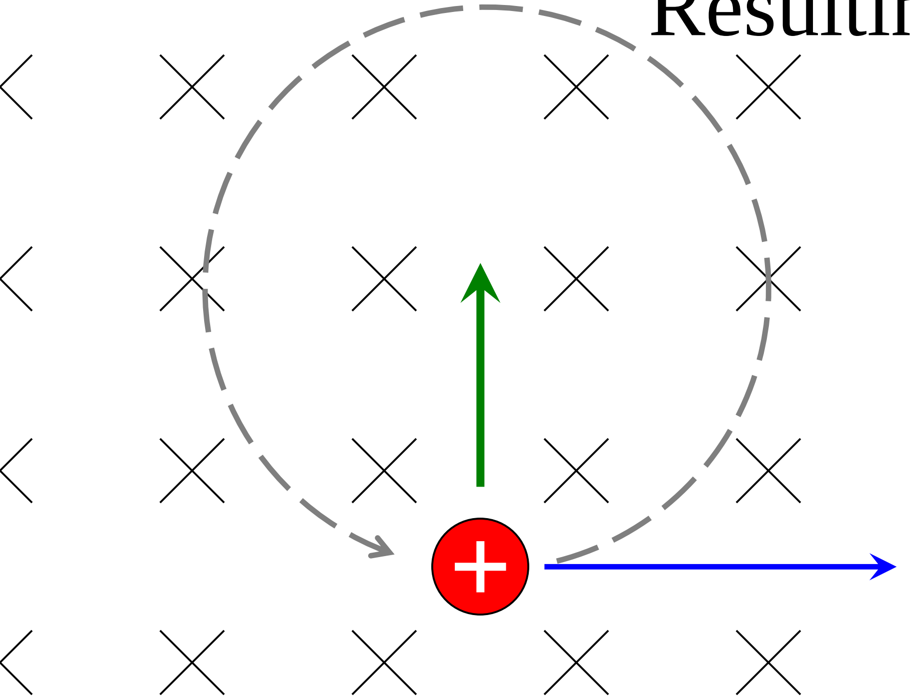
A moving charged particle has circular motion at constant speed in a uniform magnetic field!
The force is always perpendicular to the velocity.

Determine the magnetic force:



Same charge, double the field, what will be different?

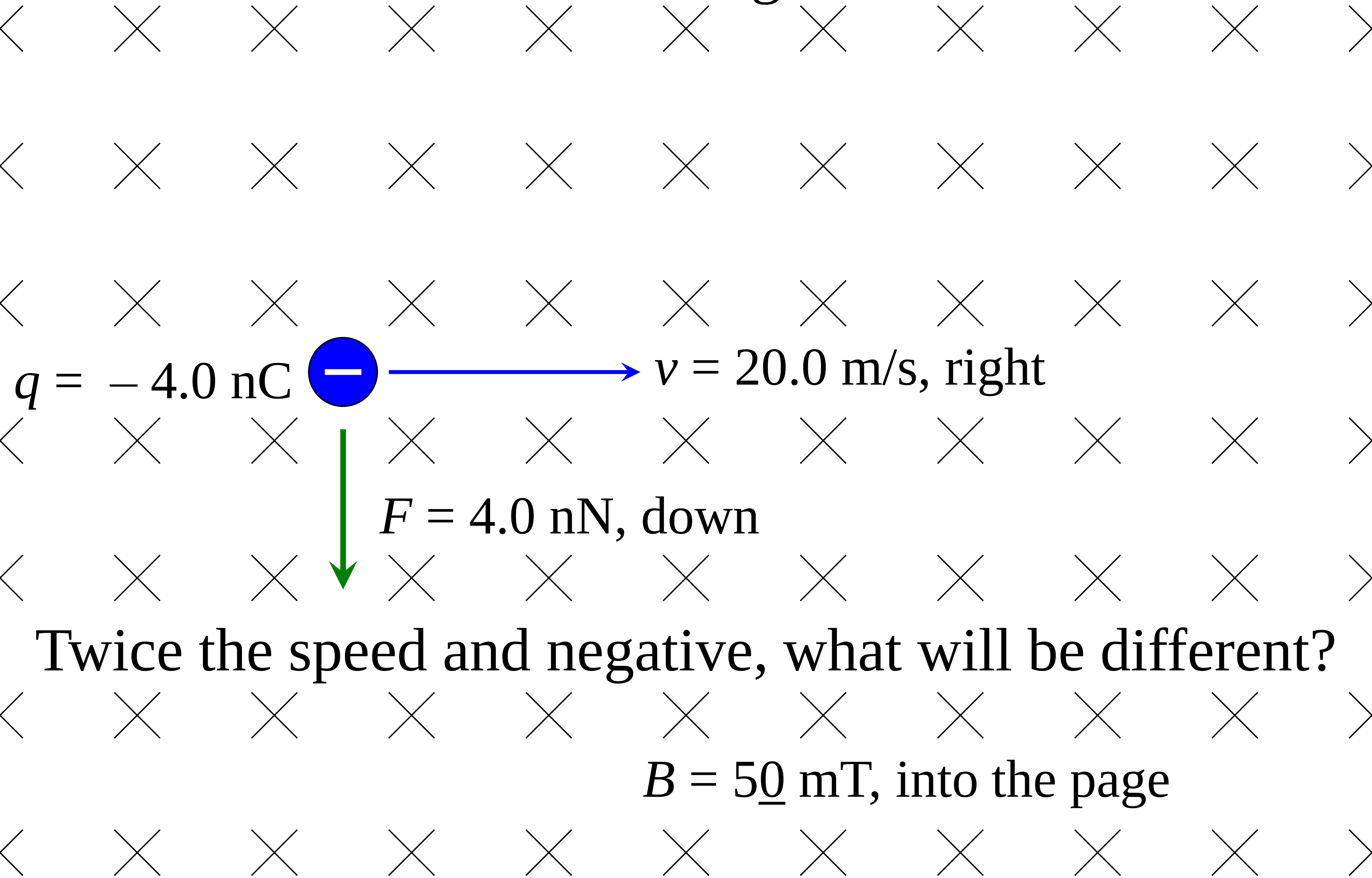
Resulting Motion:



Because the field is doubled twice as much force acts and causes greater acceleration and thus a smaller circle. Speed is unaffected!

B = 50 mT, into the page

Determine the magnetic force:

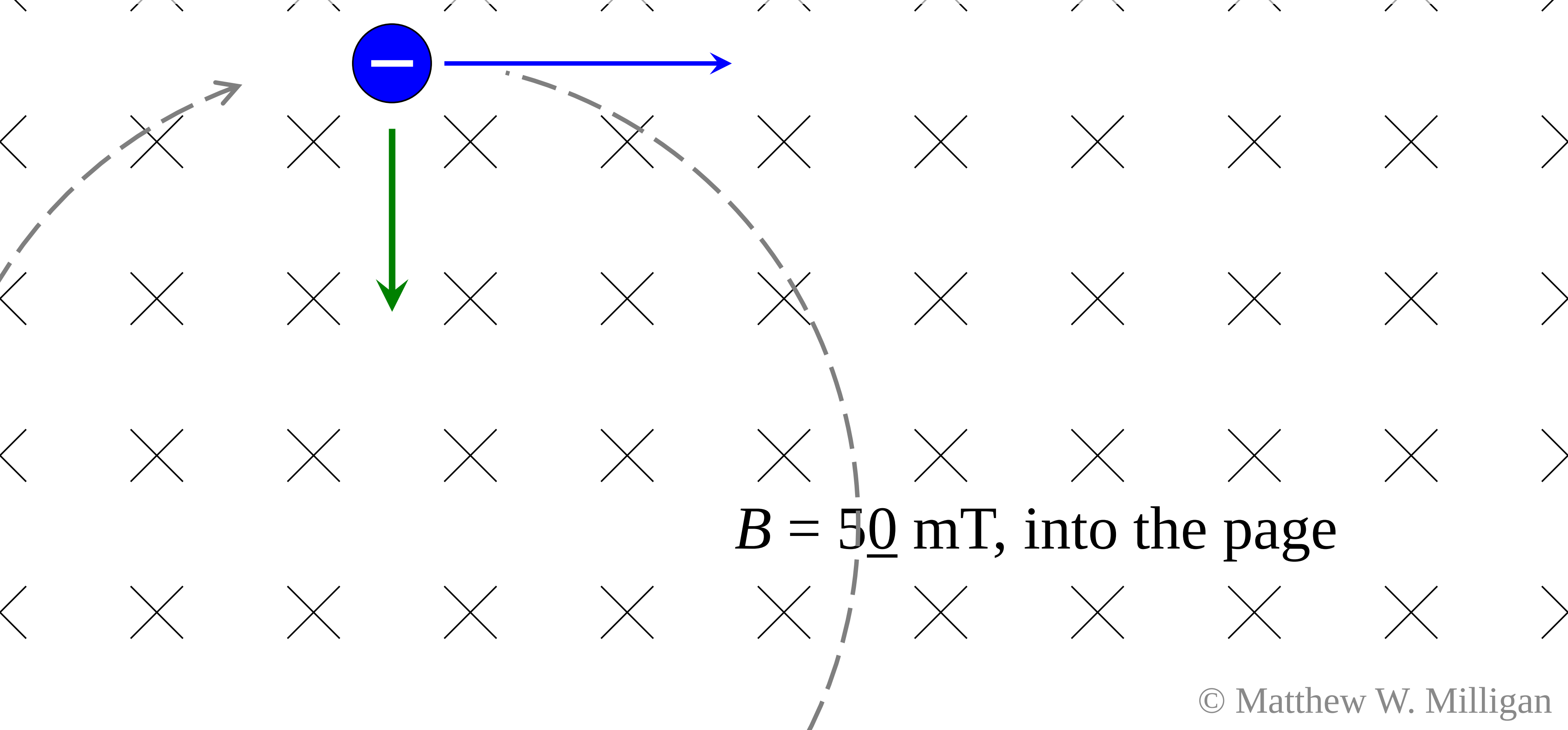


Twice the speed and negative, what will be different?

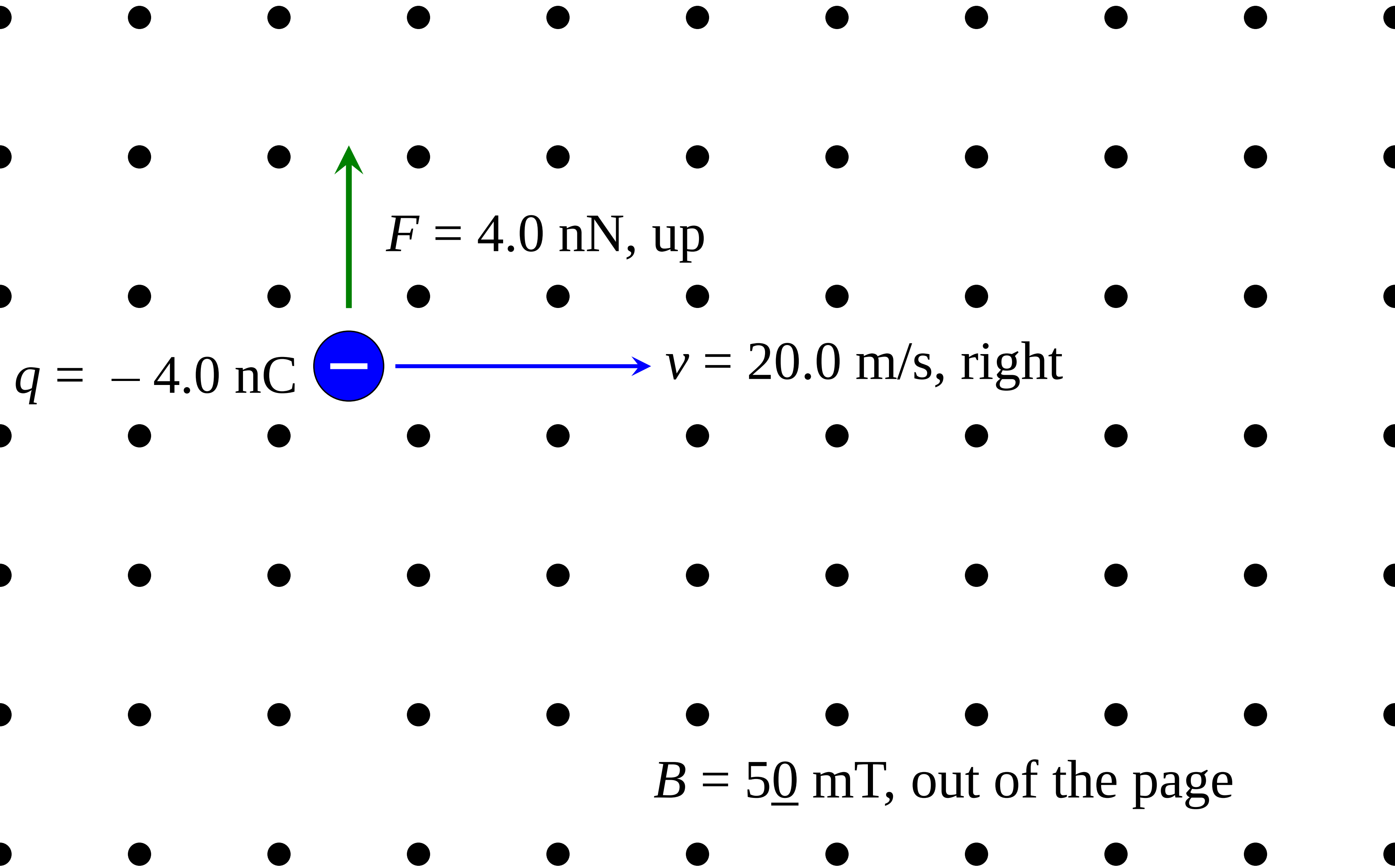
$B = 5\underline{0}$ mT, into the page

Resulting Motion:

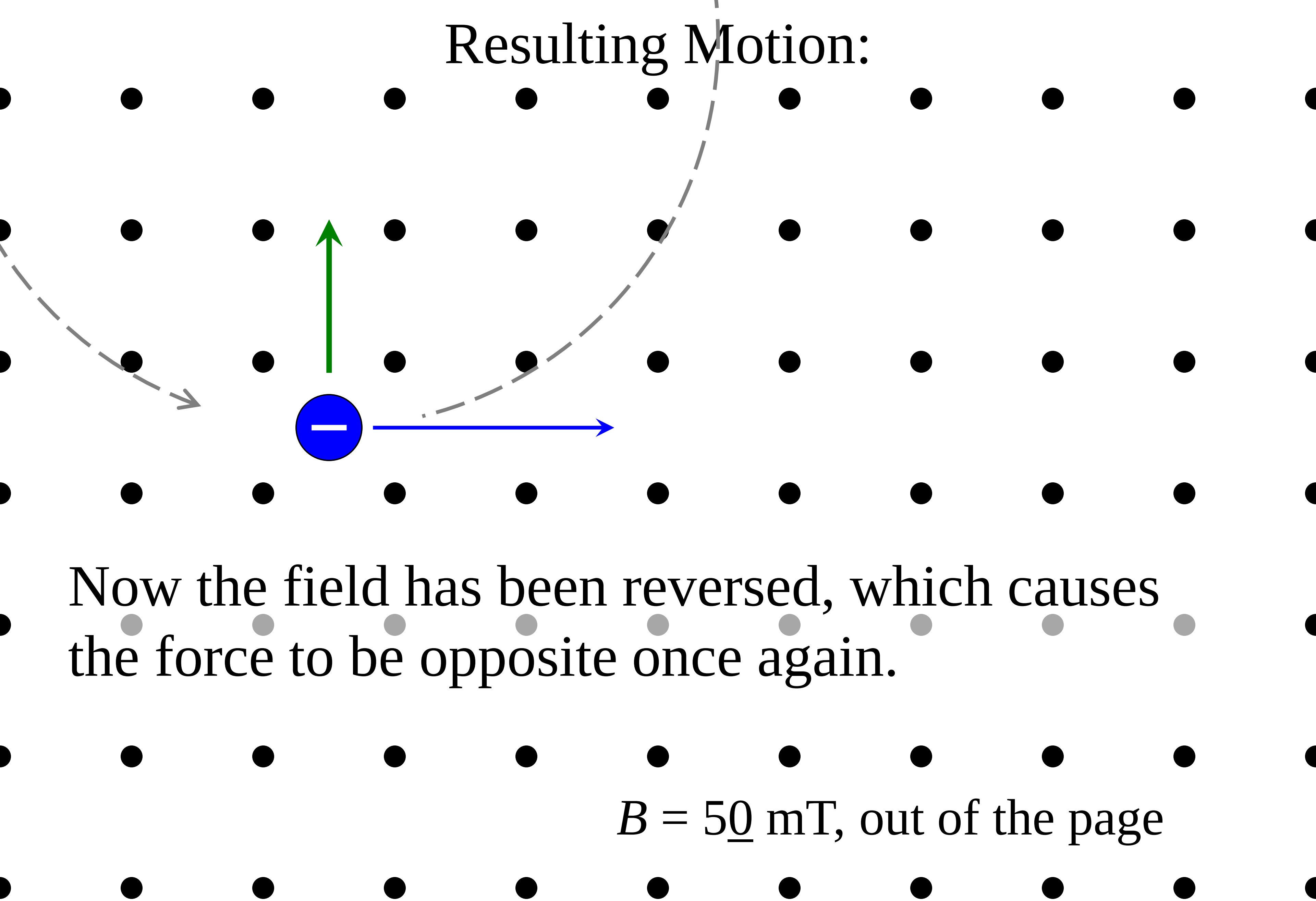
The force is same but in the opposite direction for a negative charge. Because it is moving faster the circle is larger in spite of the same acceleration.



Determine the magnetic force:



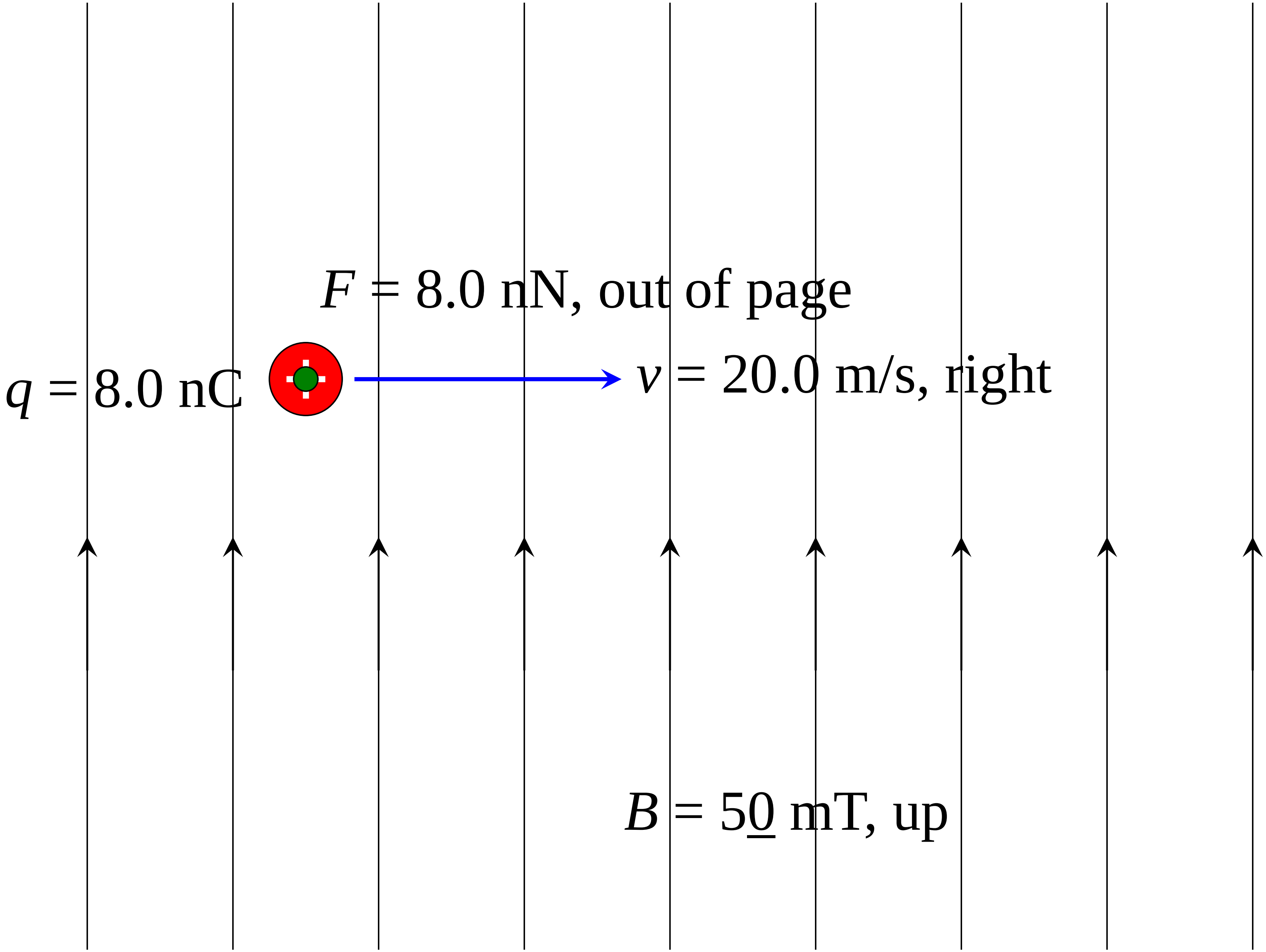
Resulting Motion:



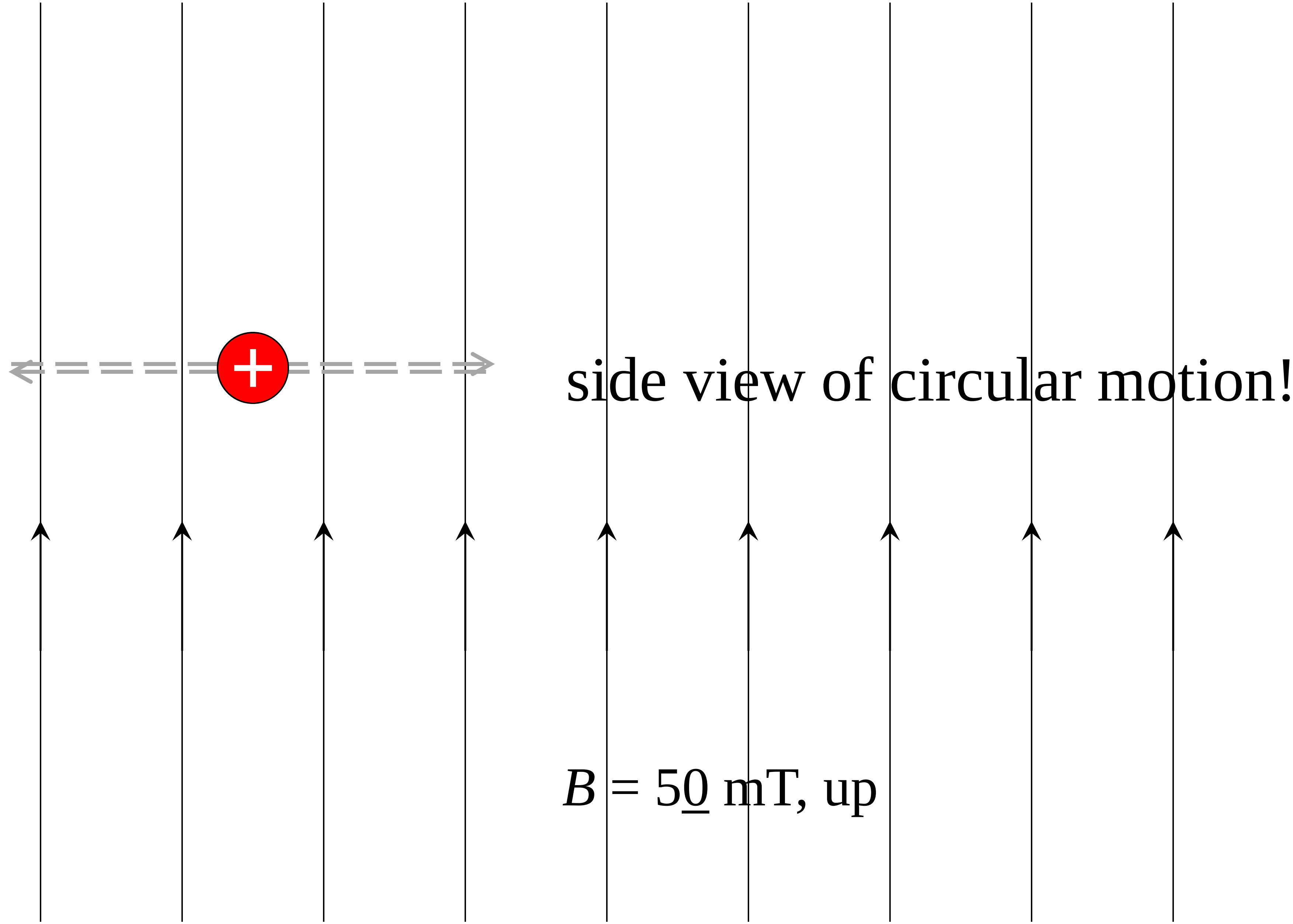
Now the field has been reversed, which causes the force to be opposite once again.

$B = 50$ mT, out of the page

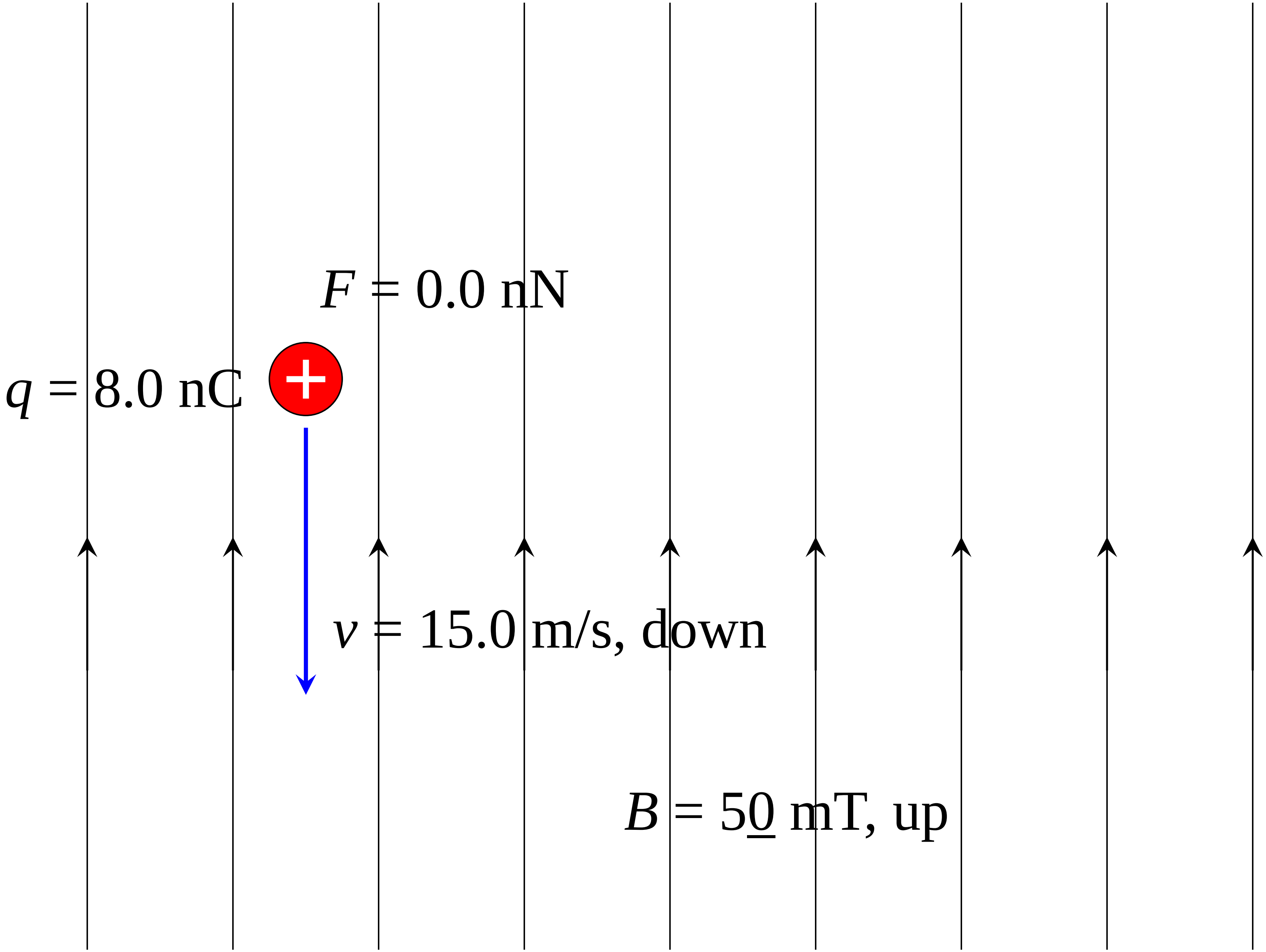
Determine the magnetic force:



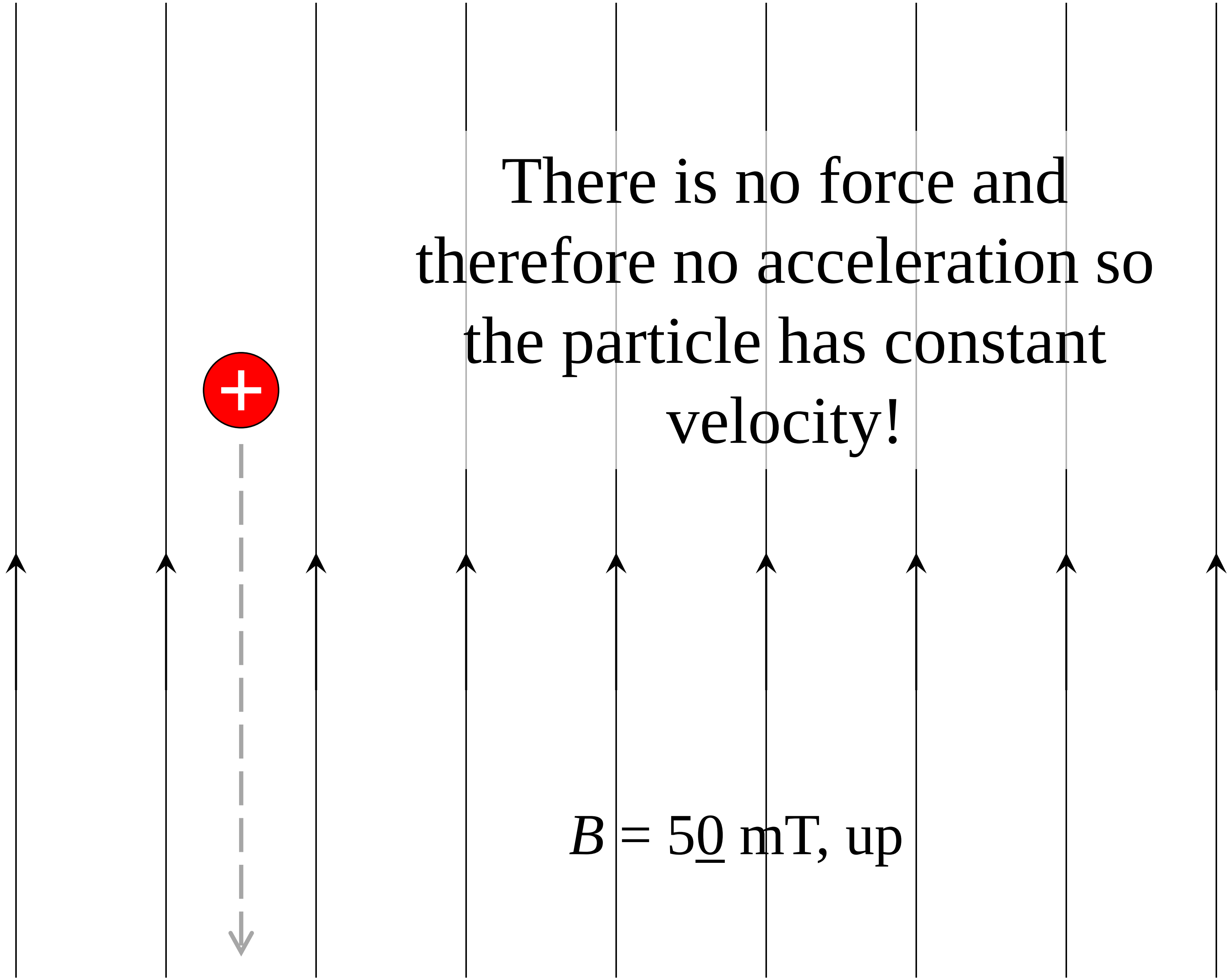
Resulting Motion:



Determine the magnetic force:

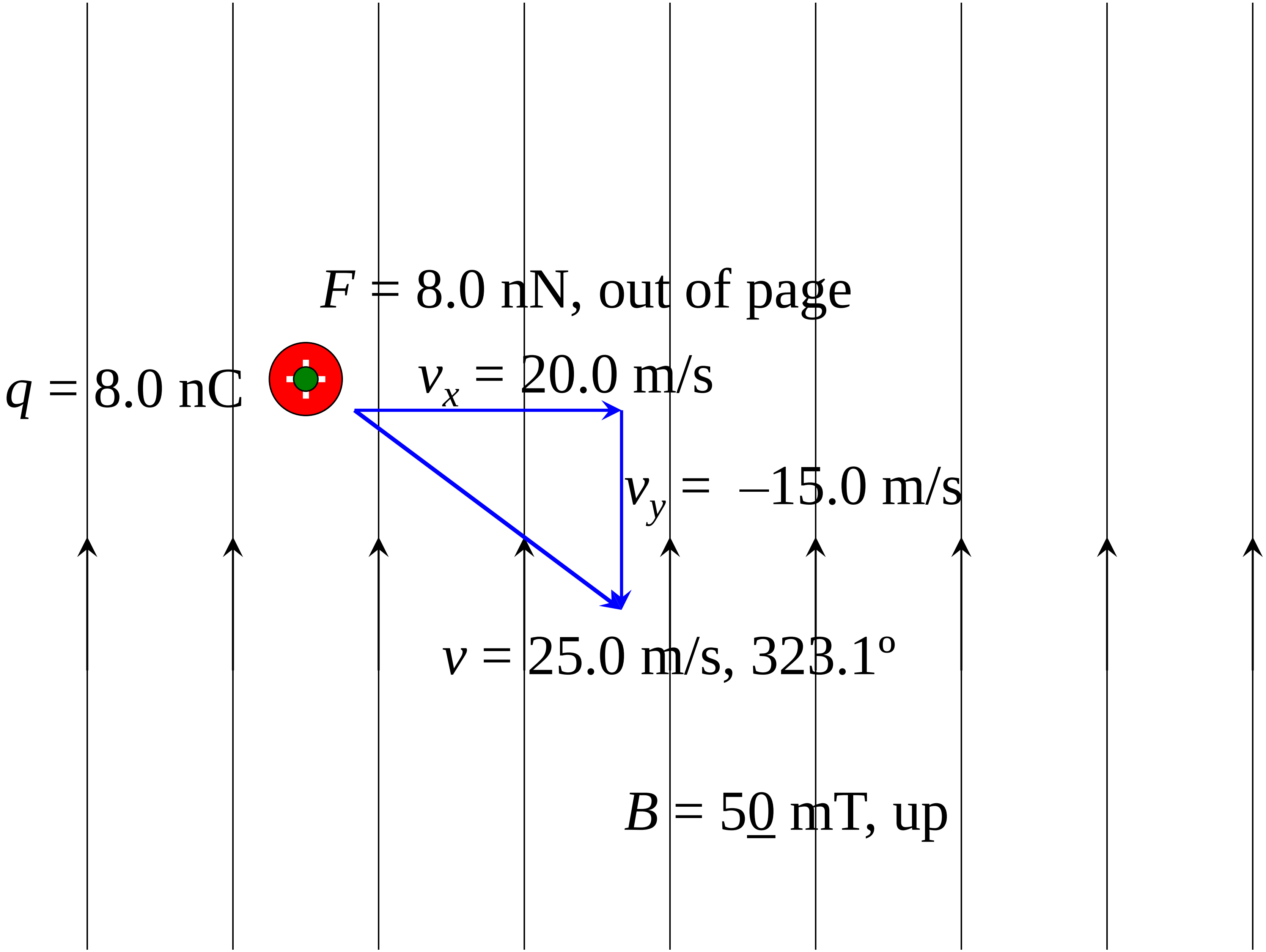


Resulting Motion:

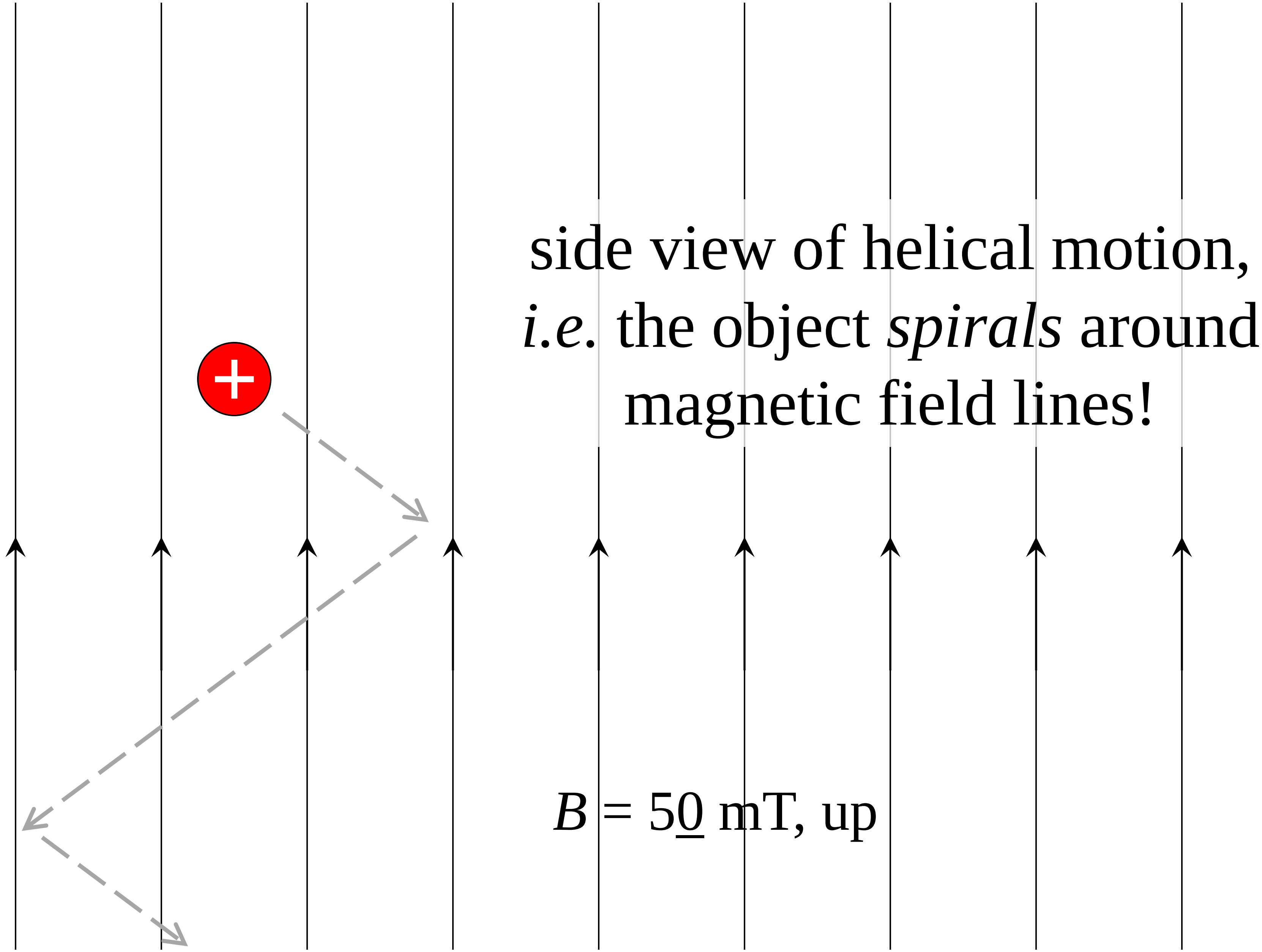


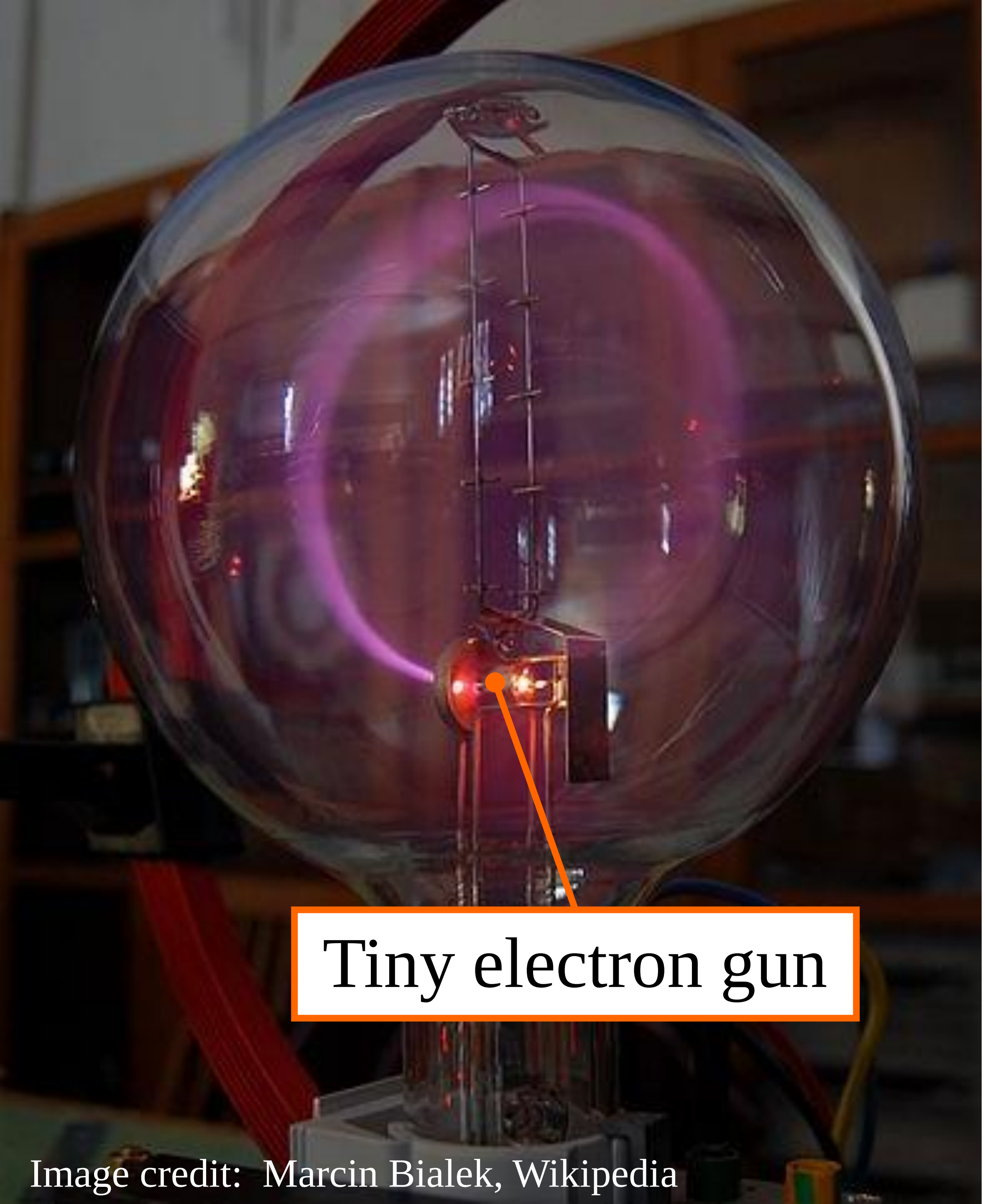
There is no force and therefore no acceleration so the particle has constant velocity!

Determine the magnetic force:



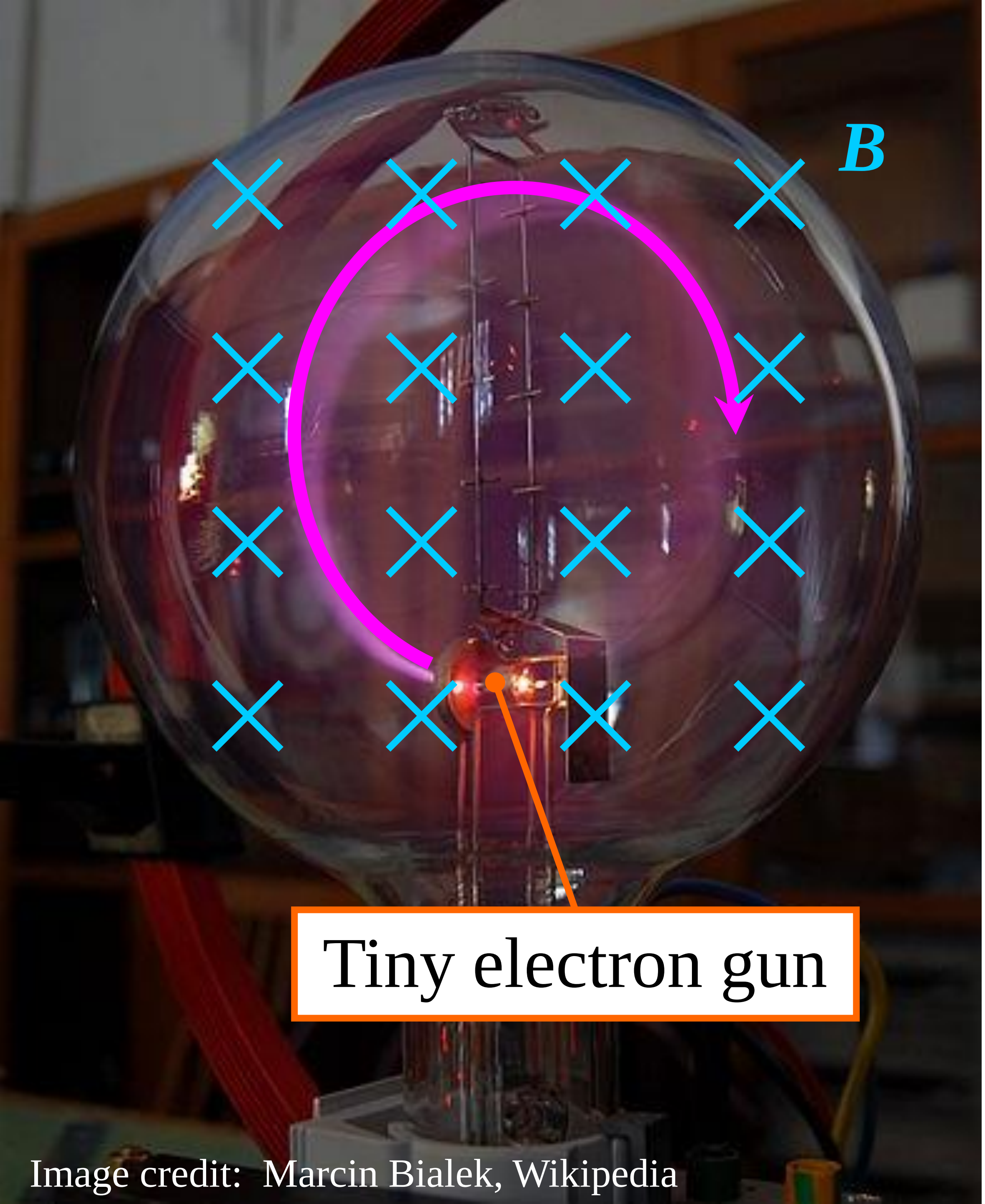
Resulting Motion:





Electrons are responsible for the glowing circle!

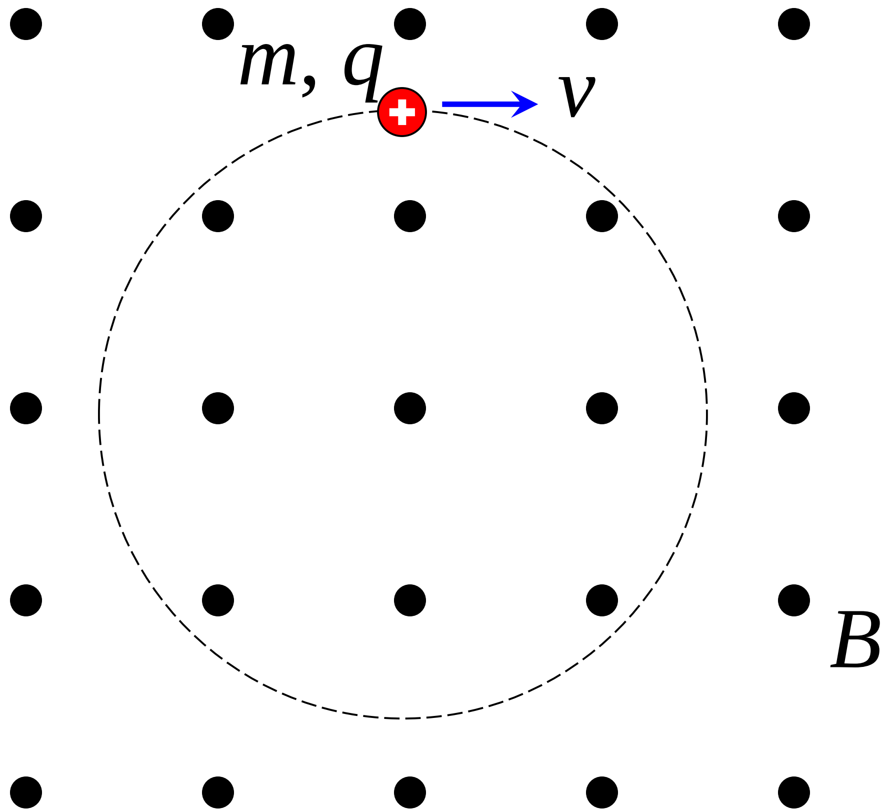
In what direction must the magnetic field point to cause the electrons to circle clockwise like this?



Electrons are responsible for the glowing circle!

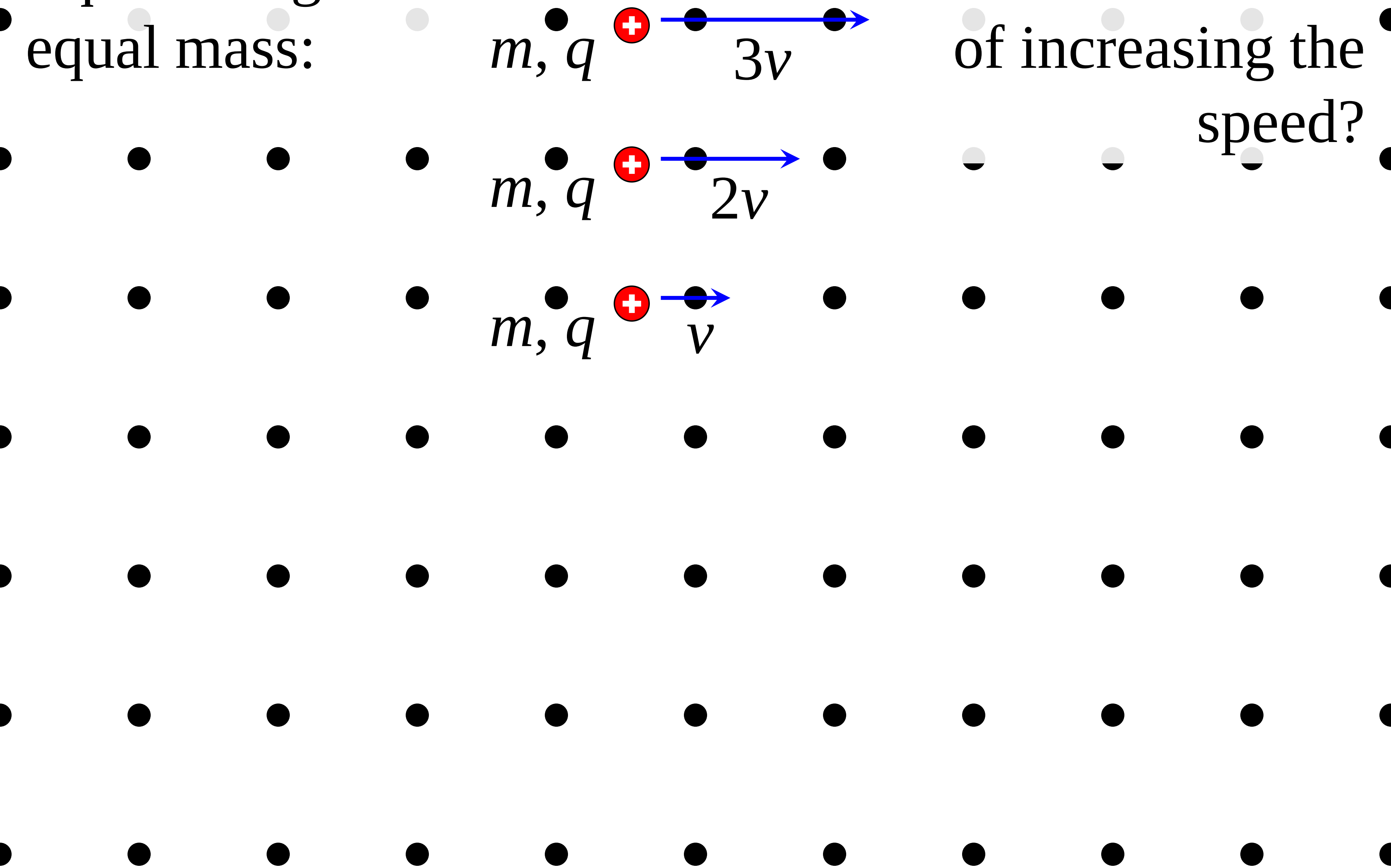
The magnetic field is perpendicular to the circle and away from our view or “into the page”.

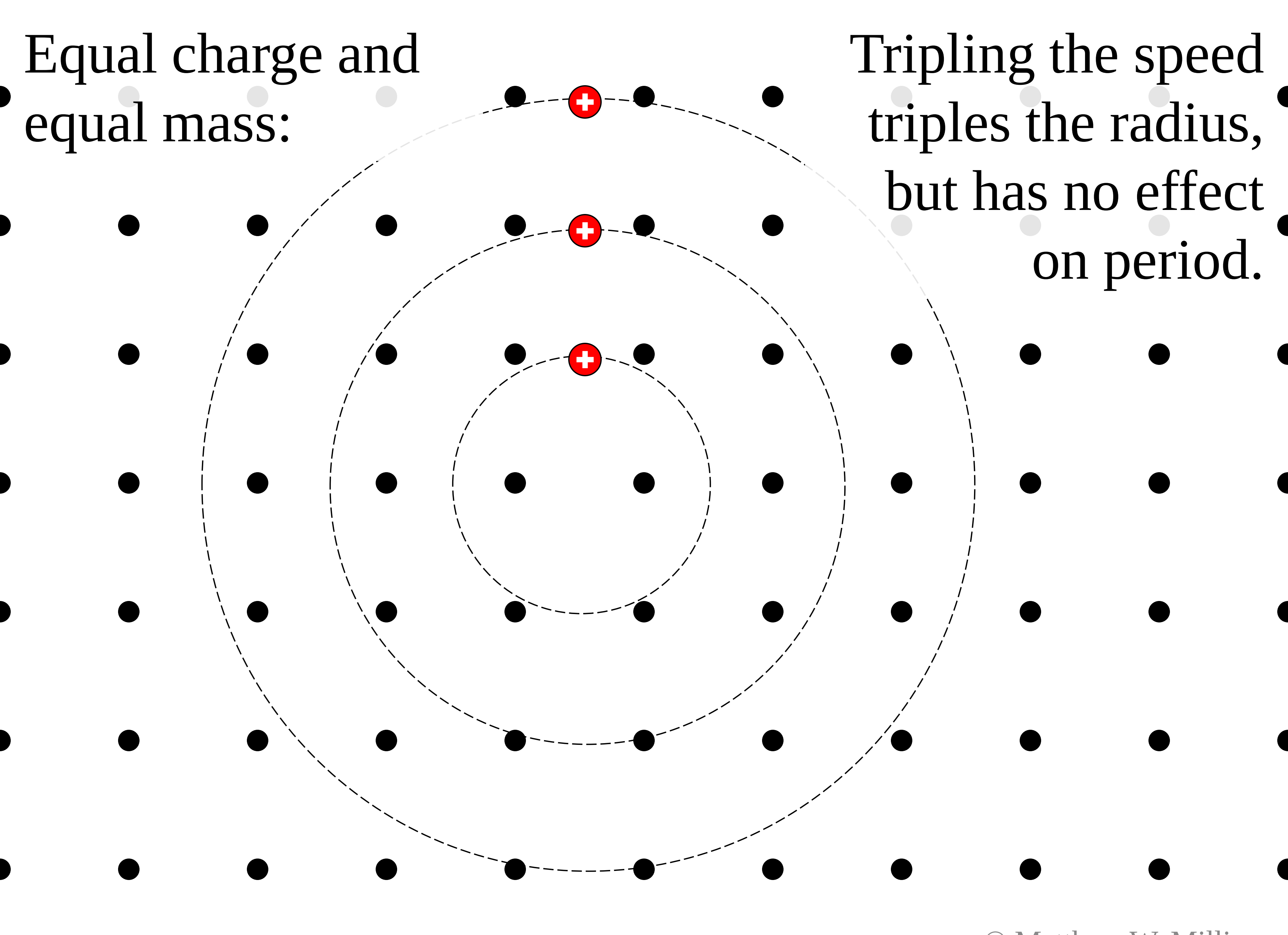
A particle of mass *m* and charge *q* undergoes circular motion at speed *v* in a uniform magnetic field *B*. Determine the radius and period of this motion.



Equal charge and equal mass:

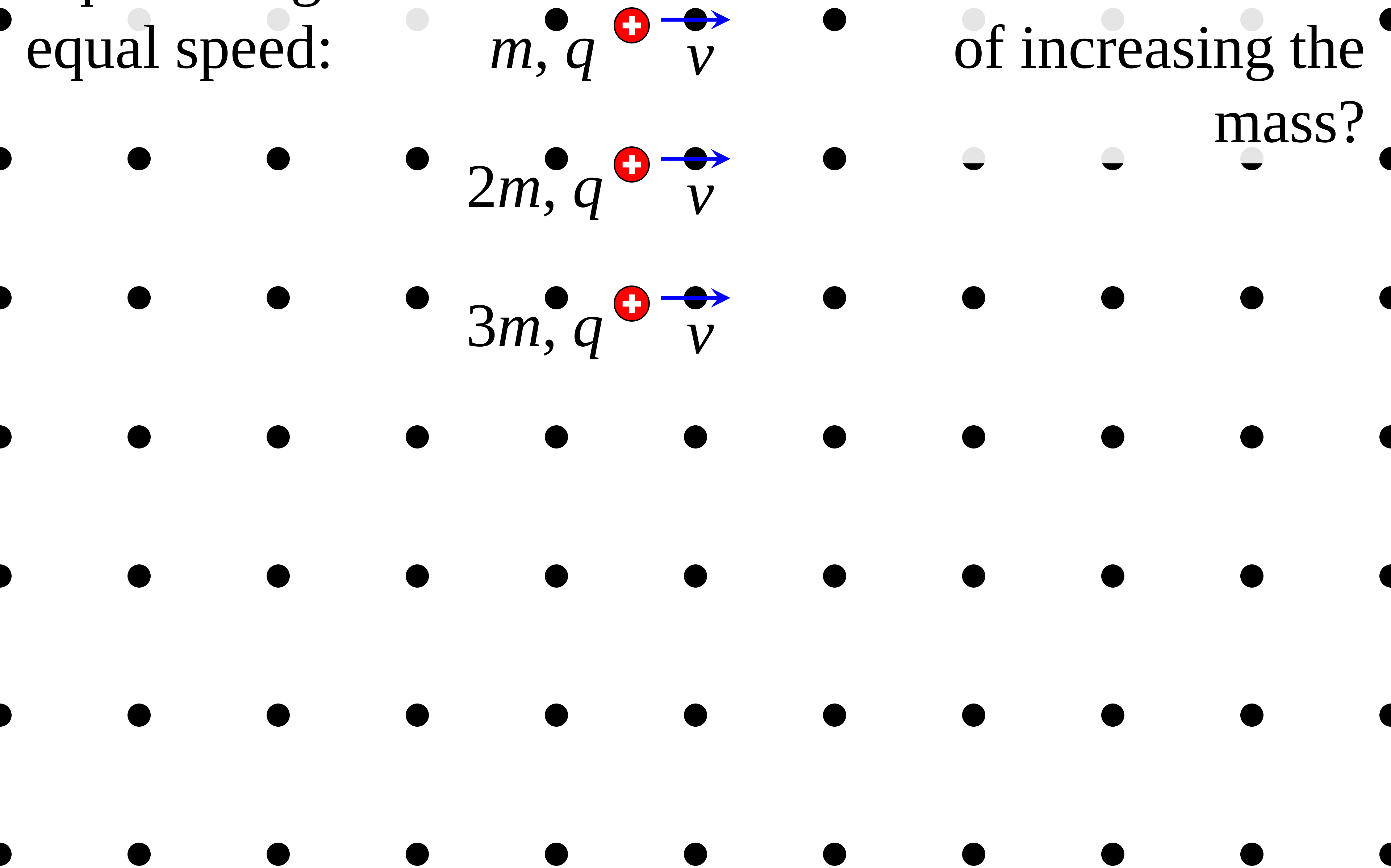
What is the effect of increasing the speed?




Equal charge and equal mass:
Tripling the speed triples the radius, but has no effect on period.

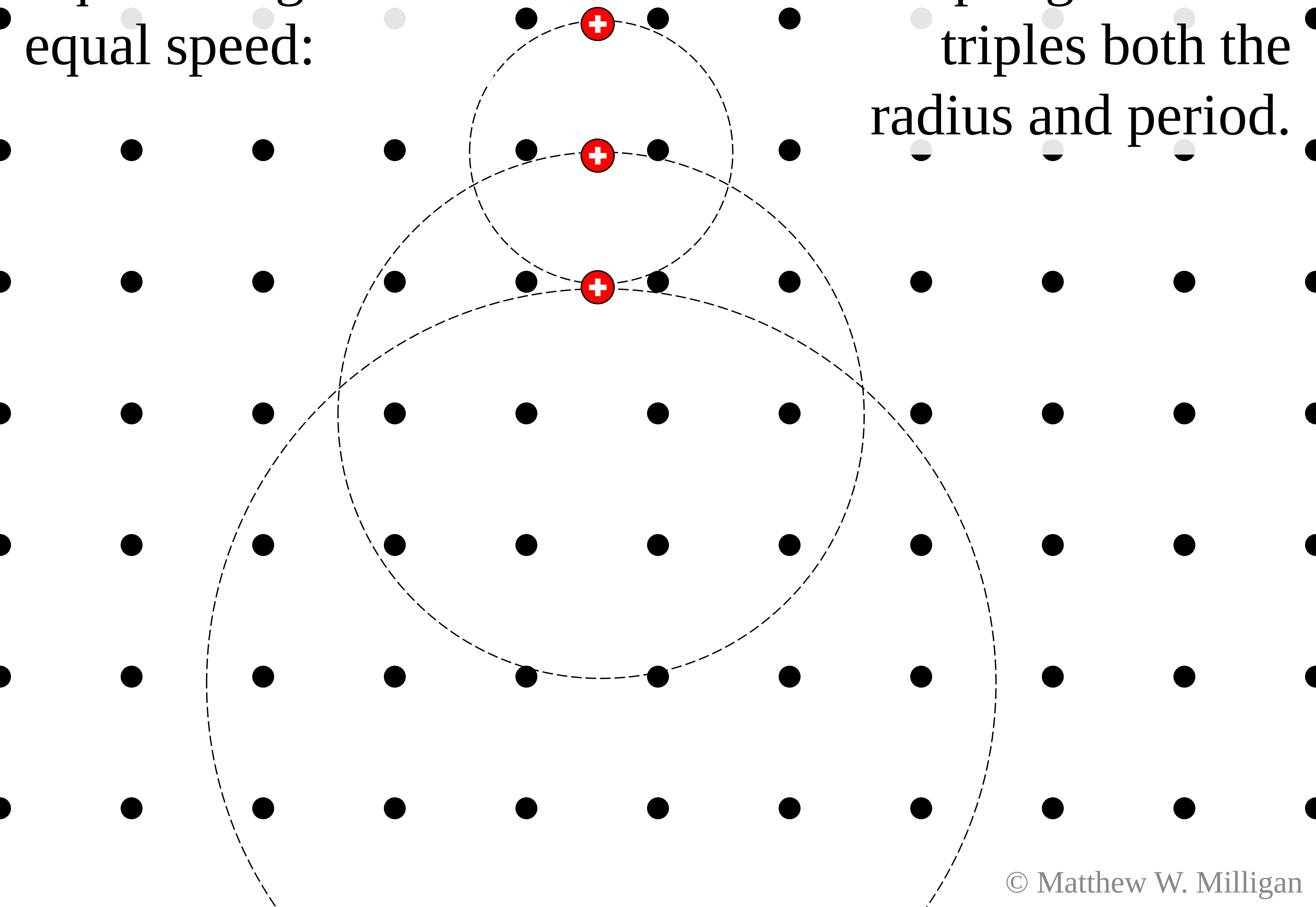
Equal charge and equal speed:

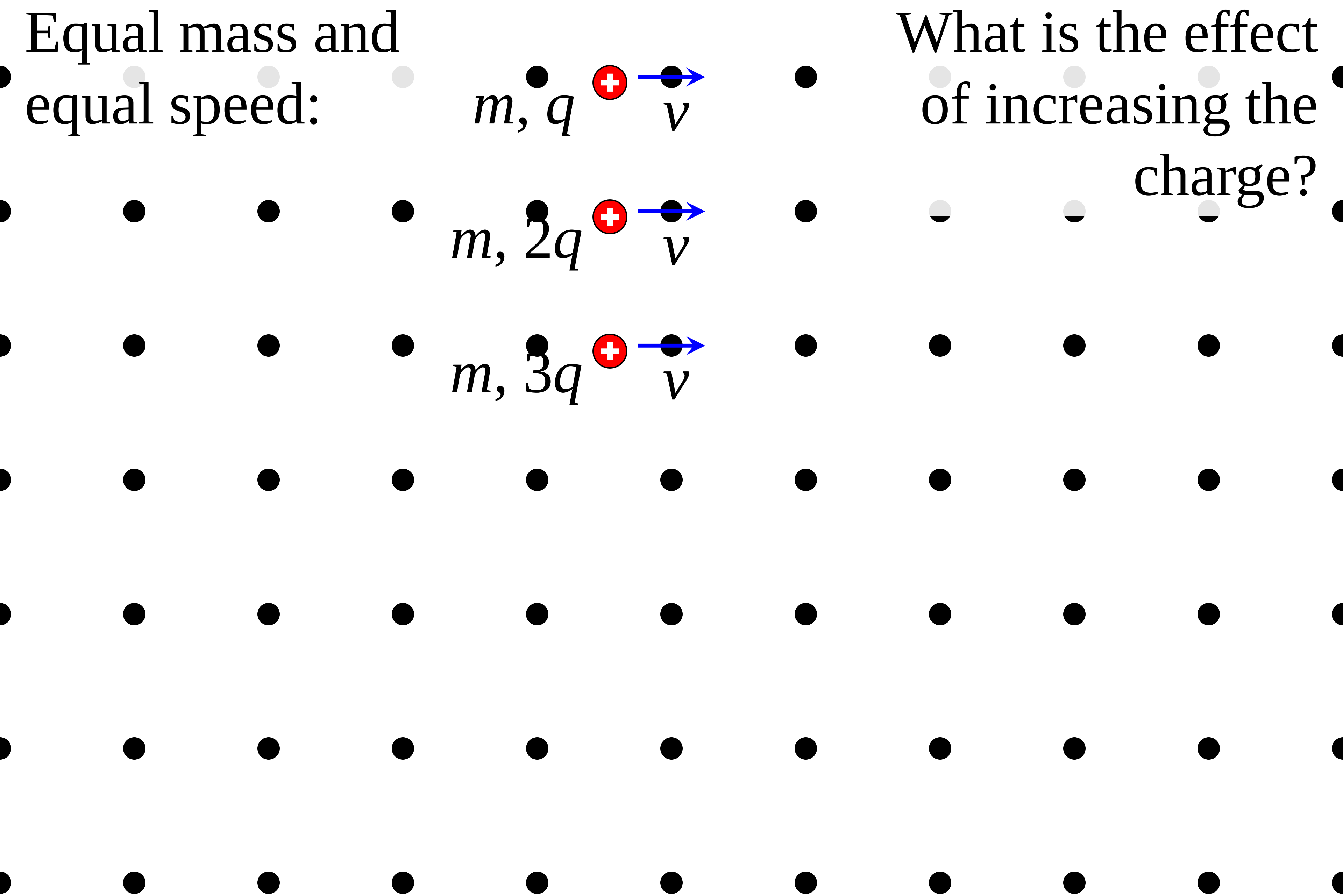
What is the effect of increasing the mass?



Equal charge and equal speed:

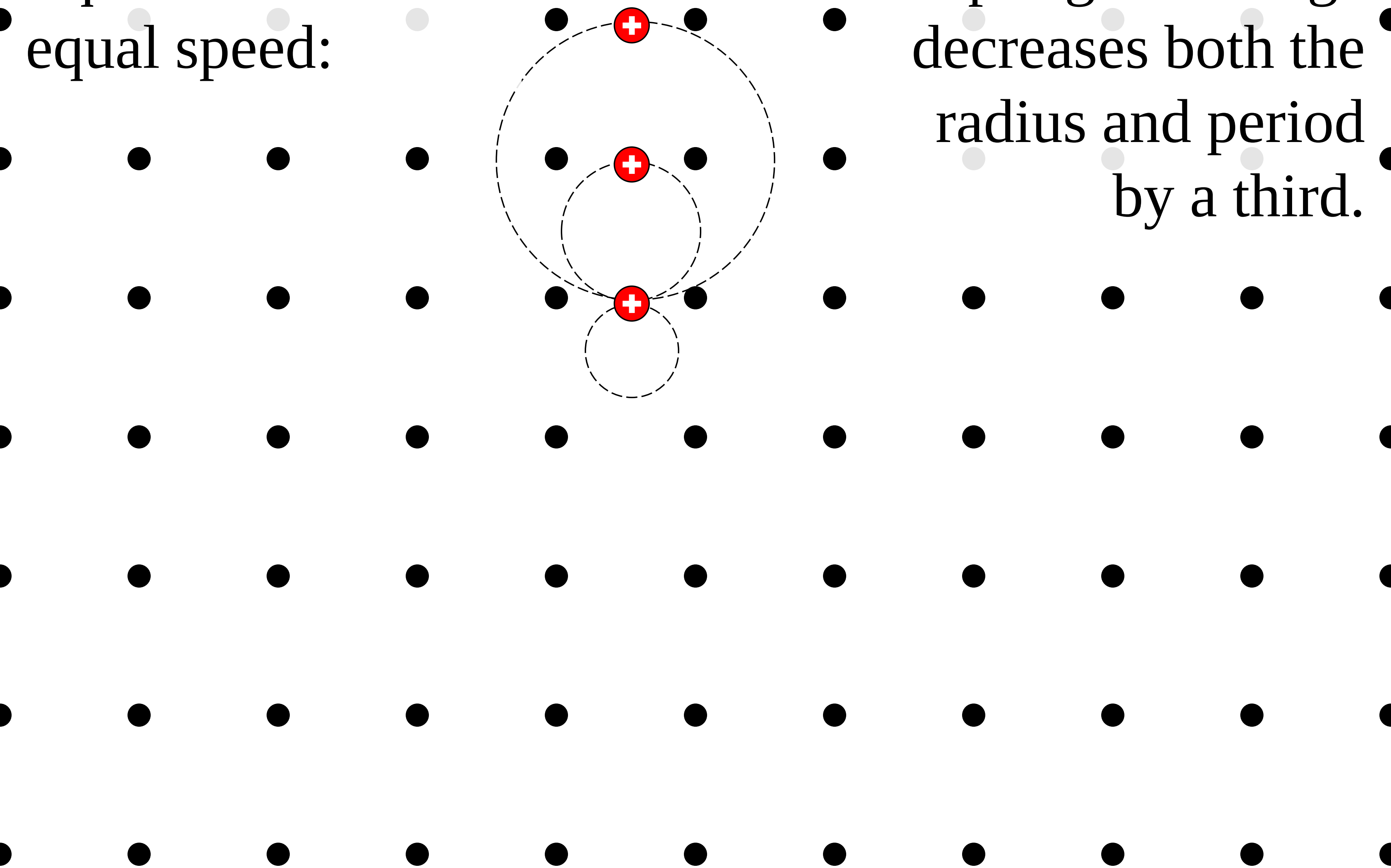
Tripling the mass triples both the radius and period.




Equal mass and equal speed:
m, q
v
m, 2q
v
m, 3q
v
What is the effect of increasing the charge?

Equal mass and equal speed:

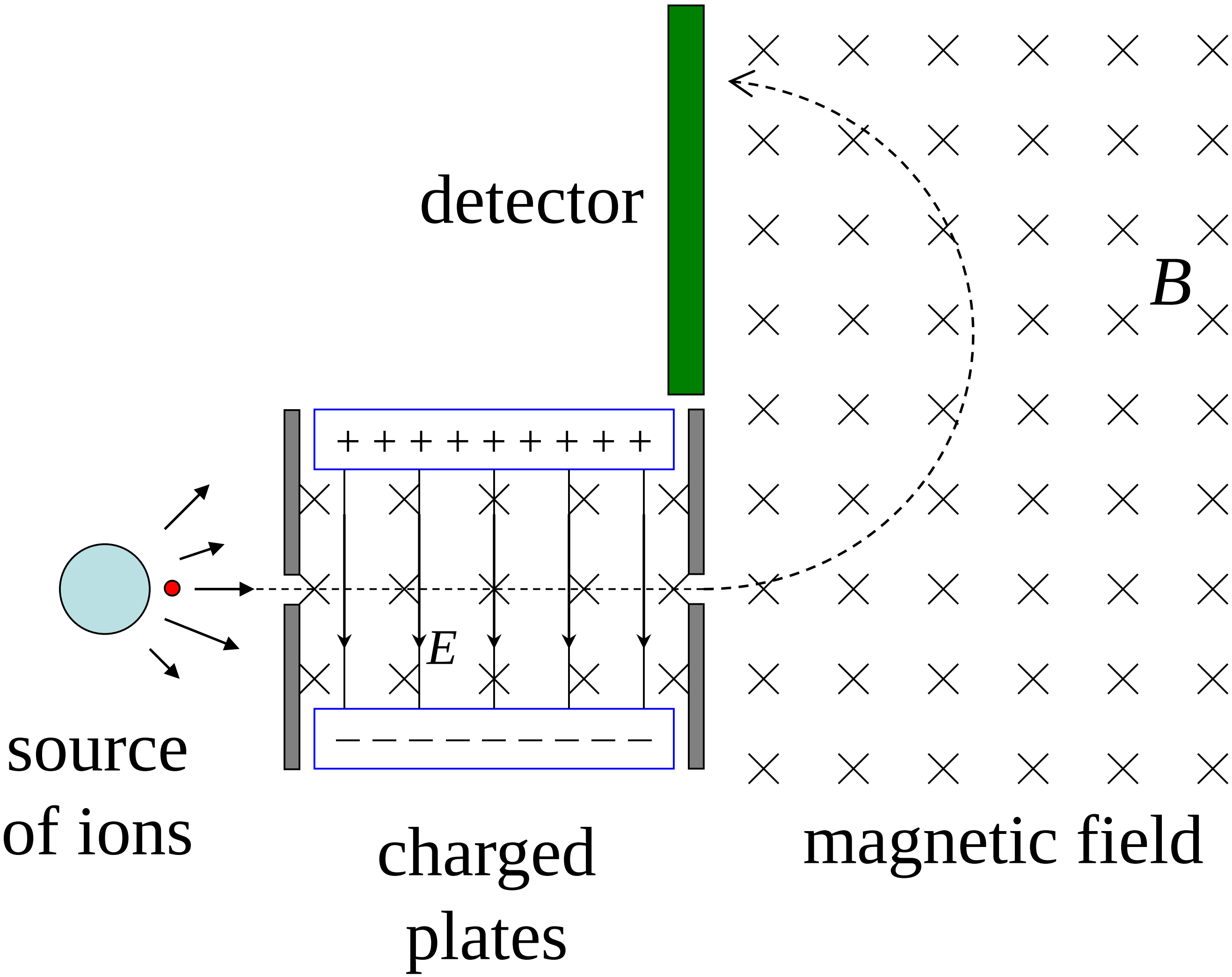
Tripling the charge decreases both the radius and period by a third.



Mass Spectrometer

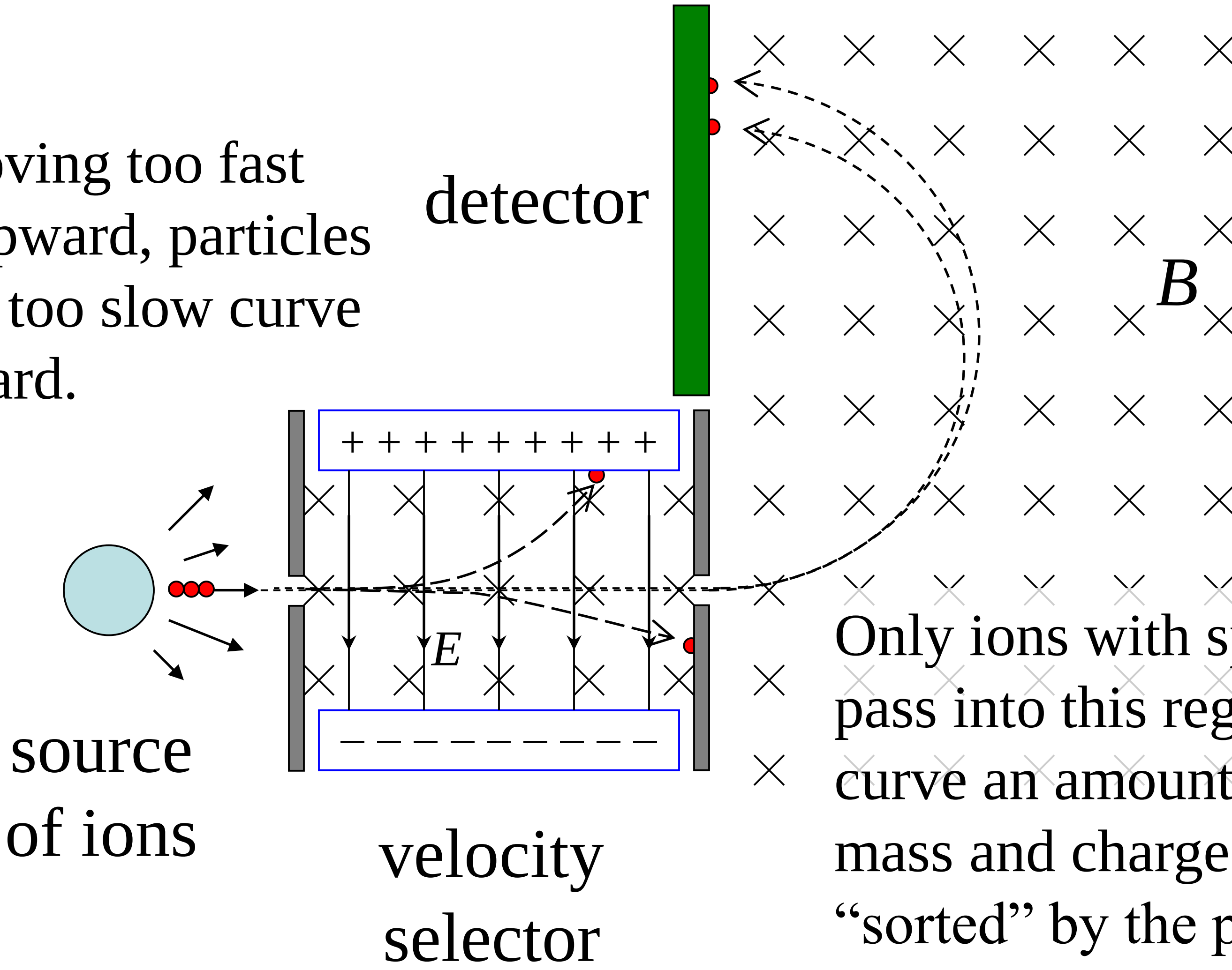
- The behavior of a charged particle moving within a magnetic field depends on its mass.
- This characteristic behavior is exploited by a mass spectrometer – a device that is used to determine the mass of ionized atoms.
- In this device ions from a certain source pass through a velocity selector and enter a region with a uniform magnetic field.
- The radius of the path within the field depends on the charge and mass of the particle.

Mass Spectrometer



Mass Spectrometer

Ions moving too fast curve upward, particles moving too slow curve downward.

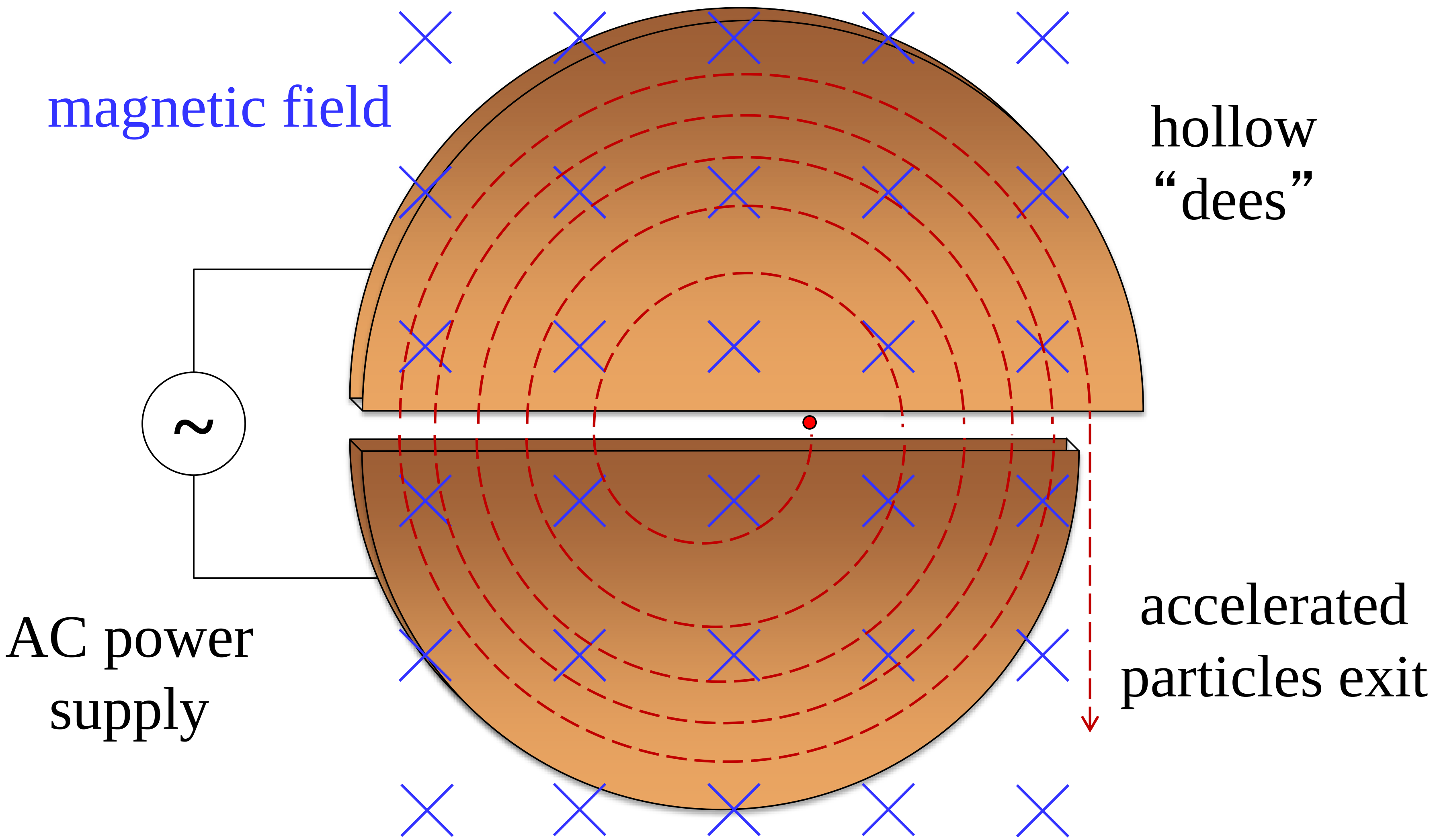


Only ions with speed $v = E/B$ pass into this region and curve an amount related to mass and charge and are "sorted" by the position of impact with detector.

Cyclotron

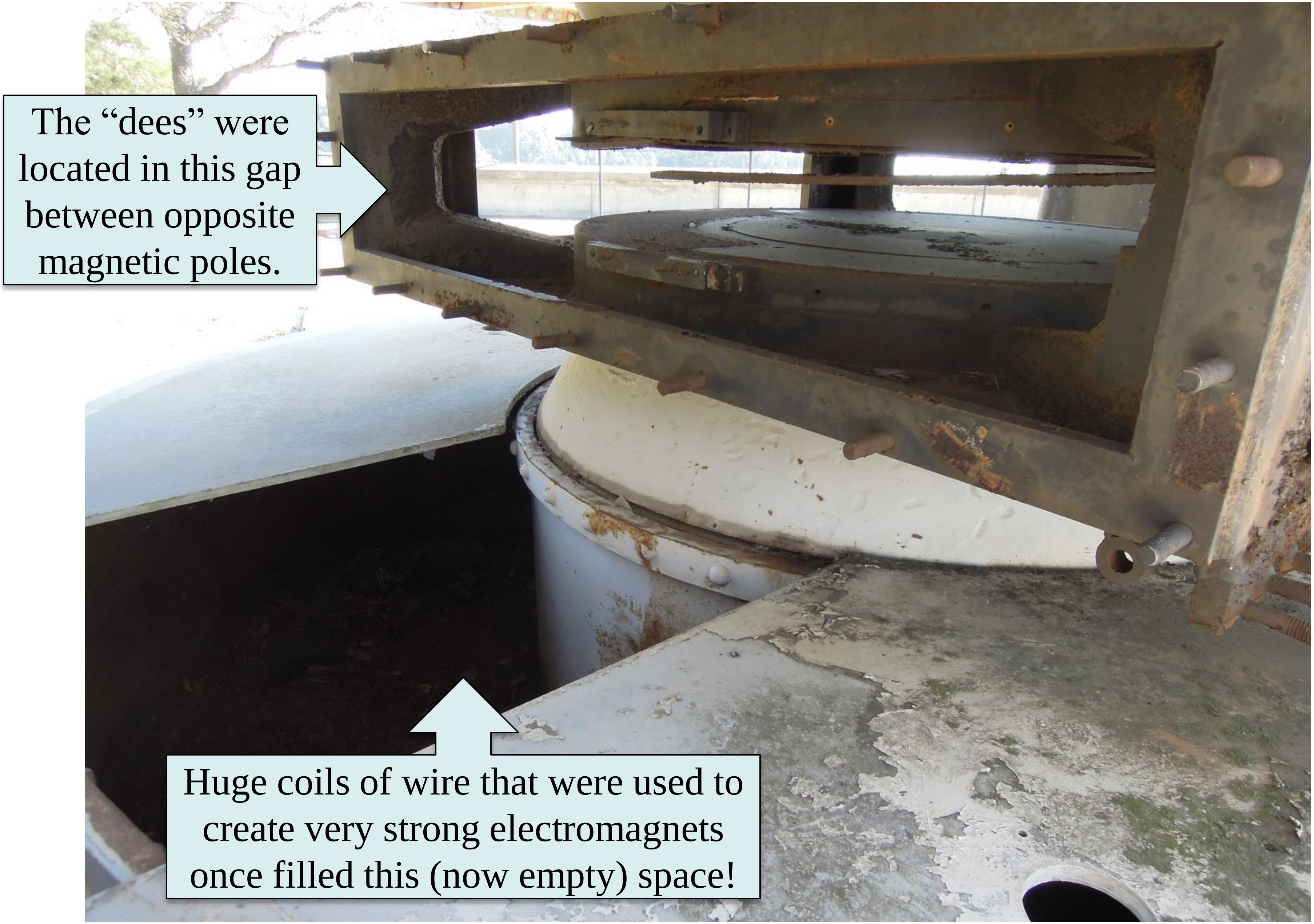
- A cyclotron is a type of particle accelerator used in particle physics.
- An electric field increases the speed of the particle as it crosses a gap between two "dees".
- A magnetic field permeating both dees causes the particle to do a "U-turn" and then cross the same gap. During the U-turn the electric field is reversed so that the particle's speed again increases.
- This cycle is repeated until the particle gains tremendous speed and exits the device.

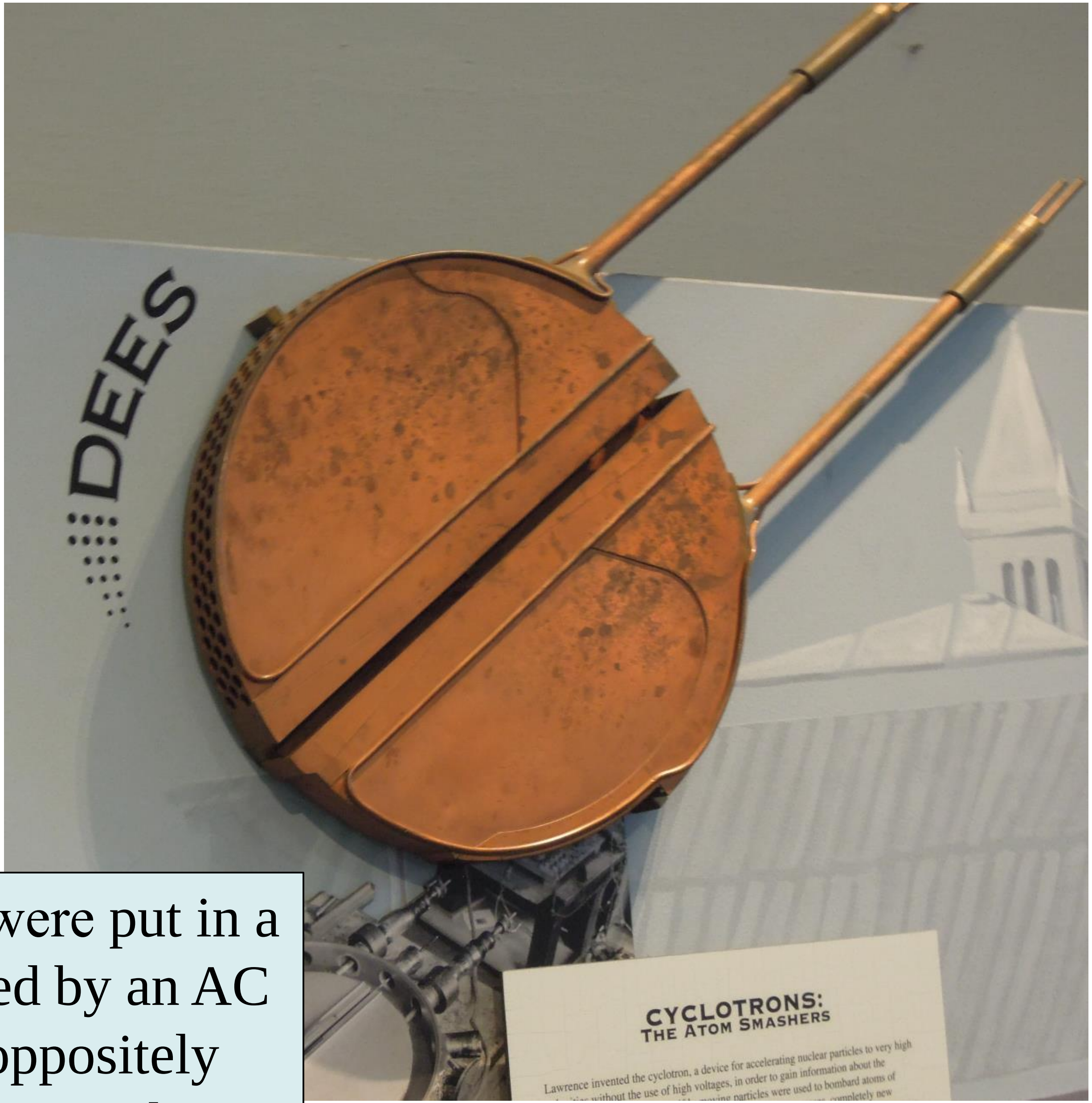
Cyclotron


magnetic field
hollow "dees"
~
AC power supply
accelerated particles exit

The 37-Inch Cyclotron at the Lawrence Hall of Science museum

Some old dude.


The “dees” were located in this gap between opposite magnetic poles.
Huge coils of wire that were used to create very strong electromagnets once filled this (now empty) space!



The hollow “dees” were put in a vacuum and powered by an AC source – always oppositely charged and alternating polarity.