University of Calgary

Department of Physics and Astronomy

PHYS 259, Winter 2017

Labatorial 9: Magnetic Force and Torque on a Loop

An electric motor converts electrical energy into mechanical energy. It may be powered by direct current or alternating current. Electric motors are used in applications as diverse as household appliances, power tools, disk drives, fans, pumps, automotive motors for seats, windows or blowers, electric vehicles, or toys. The figure shows several electric motors, with a 9V battery in the middle to illustrate the scale. The largest motor is a three phase AC induction motor, and the small ones are from a CD player or a toy.

Learning Goals:

To understand the forces and the torque that a current-carrying loop experiences in a magnetic field, and how this is used in a DC motor.

Preparation:

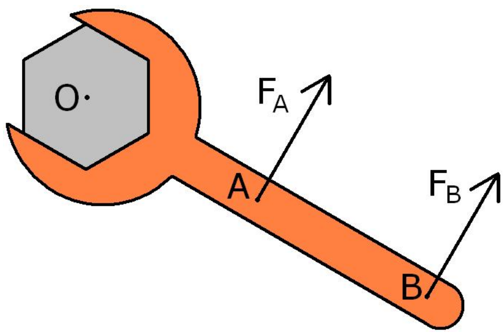
Halliday, Resnick, and Walker, "Fundamentals of Physics" 10th edition, Wiley: 28.6–28.8

Equipment:

Anatek power supply, high current power supply, motor-generator apparatus with brake, rubber mat, Fluke multimeter, connecting leads.

Note that there is an equation sheet at the end of this worksheet.

1 Mechanics Review: From force to torque



Question 1: When a net force $\vec{F}_{net}$ acts on a body, that body will experience an acceleration $\vec{a}$. In order to get an angular acceleration α, i.e. to make a body rotate, a force $\vec{F}$ must be applied in a specific way that it generates a torque $\vec{\tau} = \vec{r} \times \vec{F}$, where $\vec{r}$ is the lever arm and represents the vector from the pivot point to where the force acts.

a) Look at the figure above: if you want to loosen the bolt with a wrench, which of the two forces (of equal magnitude) is most likely to succeed, F_A or F_B? Explain.

b) Draw onto the figure an equal magnitude force that will not turn the bolt at all, and label it F_C.

c) Draw onto the figure an equal magnitude force F_D that is applied at the same point as force F_B, but produces a smaller torque.

Question 2: Sketch a situation in which two forces are acting on a rod such that the net force is zero but the net torque is not. Describe the resulting motion.

Question 3: Sketch a situation in which two forces are acting on a rod such that the net torque is zero but the net force is not. Describe the resulting motion.

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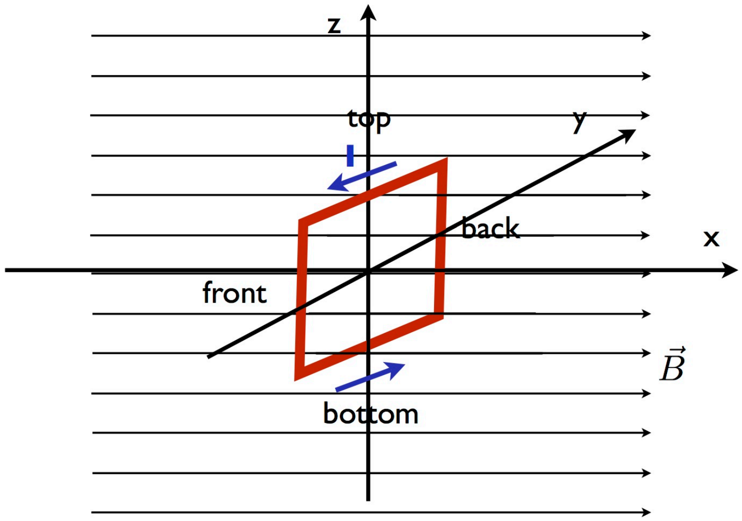
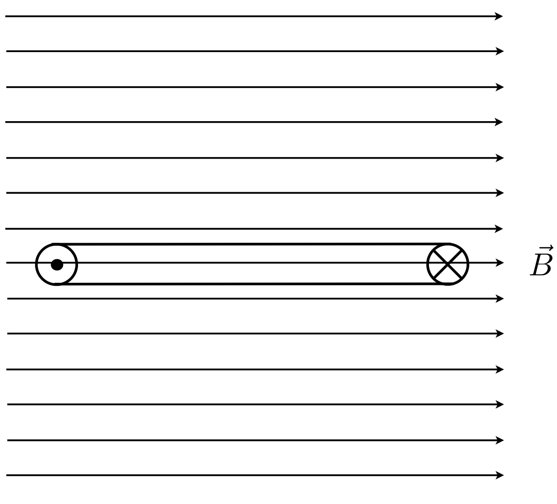
2 Magnetic forces and torque on a current-carrying loop in a uniform magnetic field



To understand how the magnetic field makes the loop rotate, we will consider the forces on each side of the loop, for different positions in the field. This figure shows a simplified view of the situation: The loop has an axle that allows it to rotate about the y-axis, and the current runs through it as indicated by the arrows. The side length of the loop is L. The uniform magnetic field is in the x-direction.



Question 4: This figure shows the loop viewed edge-on and aligned with the x-axis. You are looking at what we called the "front" part of the loop in the previous figure. The dot and cross indicate the direction of the current: the current comes out of the paper on the left (the side labeled "top" in the previous figure), flows across the front of the loop, and enters the paper on the right (the side labeled "bottom" in the previous figure).

a) Write down expressions for the force on each part of the loop, in terms of the current I, the magnetic field strength B, and the length L of the sides of the loop. Use unit vectors to indicate the direction.

$\vec{F}_{front} =$

$\vec{F}_{back} =$

$\vec{F}_{top} =$

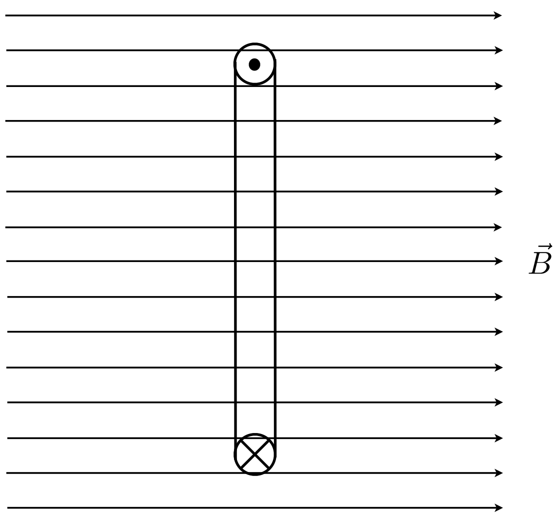
$\vec{F}_{bottom} =$

b) What is the sum of the forces acting on the loop?

c) Calculate the net torque (magnitude and direction) from the expressions for the individual forces that you found in part (a).

d) In the figure, sketch the direction of the magnetic dipole moment $\vec{\mu}$ of the loop. Calculate the torque from the expression $\vec{\tau} = \vec{\mu} \times \vec{B}$, and check whether or not your result is the same as in part (c).

CHECKPOINT 1: Before moving on to the next part, have your TA check the results you obtained so far.



Question 5: This figure shows the loop viewed edge-on, now aligned along the z-axis. Here, the "bottom" and "top" sides of the loop are on the bottom and top respectively.

a) Write down expressions for the force on each part of the loop, in terms of the current I, the magnetic field strength B, and the length L of the sides of the loop. Use unit vectors to indicate the direction.

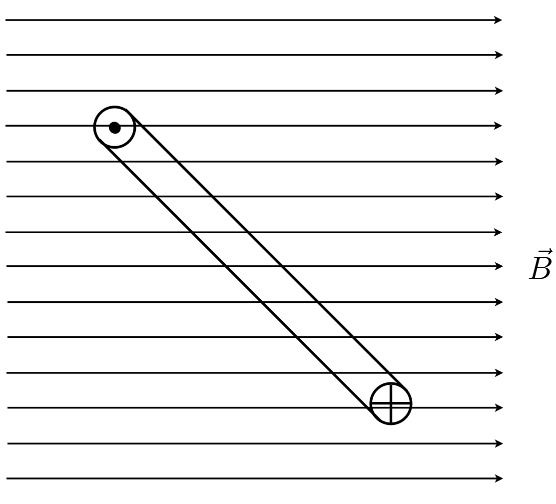
$\vec{F}_{front} =$ $\vec{F}_{back} =$

$\vec{F}_{top} =$ $\vec{F}_{bottom} =$

b) What is the sum of the forces acting on the loop?

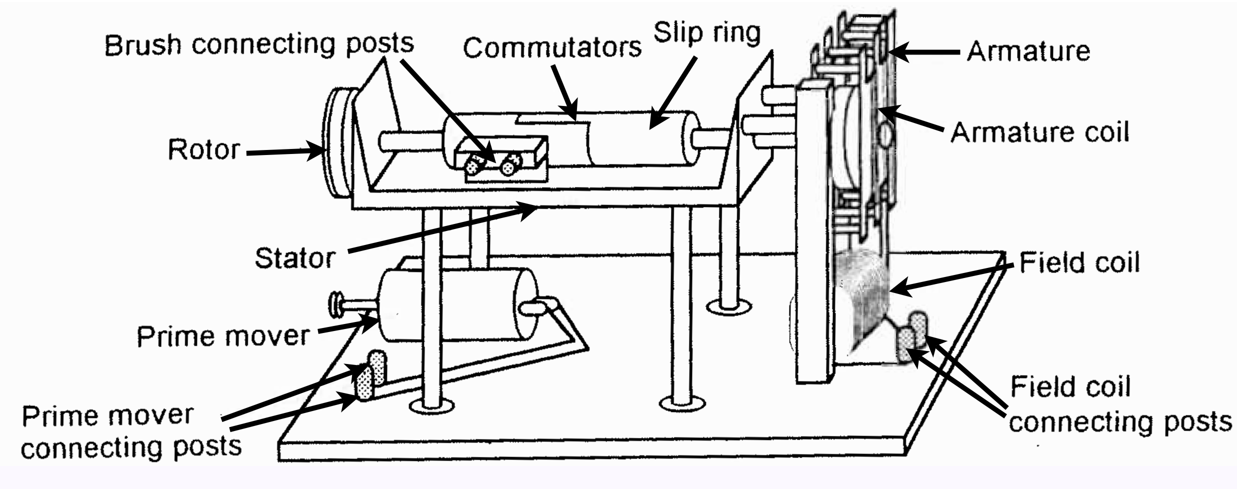
c) Calculate the net torque (magnitude and direction) from the expressions for the individual forces that you found in part (a).

d) In the figure, sketch the direction of the magnetic dipole moment $\vec{\mu}$ of the loop. Calculate the torque from the expression $\vec{\tau} = \vec{\mu} \times \vec{B}$, and check whether or not your result is the same as in part (c).



Question 6: This figure shows the loop in a general orientation in the magnetic field (unlike the special cases in the previous two questions). Draw the forces on the top and bottom parts of the loop and use them to find the direction of the torque. Sketch the direction of the magnetic dipole moment $\vec{\mu}$ of the loop and indicate whether the torque from the expression $\vec{\tau} = \vec{\mu} \times \vec{B}$ agrees with the torque from the forces.

3 The basic physics of the DC Electric Motor



Question 7: Look at the motor and identify the armature coil, which corresponds to the rotating loop of the previous section. Why does the motor use a coil, instead of a single loop?

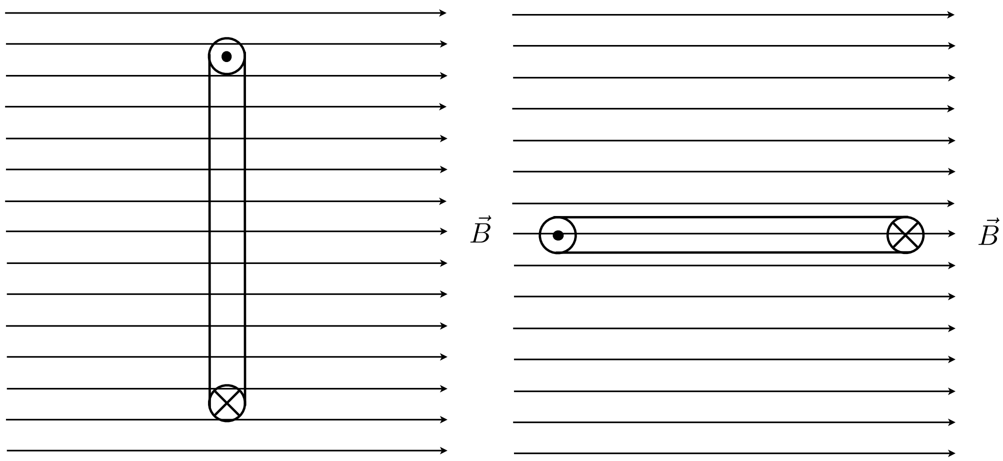
Setting up the Motor

Connect the field coil to the high current power supply and set the field coil current to about 5 A. Connect the armature to the Anatek power supply. Make sure that the brake (the two felt pads which are pressed against the rotor, to simulate a load) is loose, so that the armature is free to rotate, and that the rubber belt is disconnected.

CHECKPOINT 2: Before moving on to the next part, have your TA check the results you obtained so far.

Question 8: The field coil produces a magnetic field by passing a current through a solenoid. A U-shaped piece of iron sits inside the solenoid and redirects the magnetic field lines to pass from one end of the U to the other. Based on how the field coil is connected, what direction will the magnetic field be pointing through the loop? Be sure to include a rough sketch of the field coil (including connections to the power supply), the U-shaped piece of iron, and the armature coil.

Question 9: Put the armature coil in both positions relative to the magnetic field indicated below, then turn the motor on by setting the armature voltage to around 8 V.



a) What happens when the armature coil is started in the position on the left? Explain your observations using your previous results.

b) What happens when the armature coil is started in the position on the right? Explain your observations using your previous results.

Last Checkpoint! Clean up your area, and put the equipment back the way you found it. Call your TA over to check your work and your area before you can get credit for the labatorial.

Equations and constants

$$F_C(r) = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$$
$$\vec{E} = \frac{\vec{F}}{q}$$
$$\vec{E} = -\vec{\nabla}V$$
$$\Delta V = -\int \vec{E}\cdot d\vec{l}$$
$$\Delta U = q\Delta V$$
$$Q(t) = Q_{max}e^{-t/RC}$$
$$Q(t) = Q_{max}(1-e^{-t/RC})$$
$$C = Q/\Delta V$$
$$C = \epsilon_0 A/d$$
$$C = KC_0$$
$$U = Q^2/2C$$
$$\Delta V = RI$$
$$R = \rho L/A$$
$$\rho = E/J$$
$$P = \Delta V I$$
$$\Delta V_{bat} = \varepsilon - Ir$$
$$\vec{F} = q\vec{v}\times\vec{B}$$
$$\vec{F} = I\vec{L}\times\vec{B}$$
$$\vec{\tau} = \vec{\mu}\times\vec{B}$$
$$\vec{\mu} = I\vec{A}$$

$$F_g(r) = G\frac{m_1 m_2}{r^2}$$
$$U_{grav}(y) = mgy$$
$$K = \frac{1}{2}mv^2$$
$$v_x(t) = v_{0x} + a_x t$$
$$x(t) = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$$
$$v_x^2(t) = v_{0x}^2 + 2a_x(x(t)-x_0)$$
$$\omega = \frac{d\theta}{dt} = 2\pi f$$
$$v = \frac{2\pi r}{T} = \omega r$$
$$a_{rad} = \frac{v^2}{r} = \omega^2 r$$
$$\vec{\tau} = \vec{r}\times\vec{F}$$
$$g = 9.81\frac{m}{s^2}$$
$$G = 6.67\times10^{-11}\frac{Nm^2}{kg^2}$$
$$\frac{1}{4\pi\epsilon_0} = 8.99\times10^{9}\,Nm^2C^{-2}$$
$$\epsilon_0 = 8.85\times10^{-12}\,C^2N^{-1}m^{-2}$$
$$\mu_0 = 1.26\times10^{-6}Tm/A$$
$$e = 1.60\times10^{-19}\,C$$
$$m_e = 9.11\times10^{-31}\,kg$$
$$m_p = 1.67\times10^{-27}\,kg$$
$$m_n = 1.67\times10^{-27}\,kg$$