Physics 200 **Unit 3** Name: _____

Friction, Physics Diagrams, Circular Motion, and Gravitation

Part 1: Friction

1. The symbol that I will try to use for friction is _____What is friction?

2. The force of friction between two surfaces is determined by two things:
   - The types of materials that are in contact. Every pair of materials that are in contact has its own coefficient of friction (symbol = _____) that is proportional to the strength of the friction between them.
   - The perpendicular force that these surfaces exert on each other, which is known as the _____

3. When there is relative motion between objects in contact, the friction is called _____ friction. The symbol for its "coefficient" is _____.

4. When there is no motion between objects in contact, the friction is called _____ friction. The symbol for its "coefficient" is _____.

4. According to the table, which type of friction is stronger?

6. Write the equation for the magnitude of static friction.

7. Write the equation for the magnitude of kinetic friction.

System	Static Friction μ_s	Kinetic Friction μ_k
Rubber on dry concrete	1.0	0.7
Rubber on wet concrete	0.5-0.7	0.3-0.5
Wood on wood	0.5	0.3
Waxed wood on wet snow	0.14	0.1
Metal on wood	0.5	0.3
Steel on steel (dry)	0.6	0.3
Steel on steel (oiled)	0.05	0.03
Teflon on steel	0.04	0.04
Bone lubricated by synovial fluid	0.016	0.015
Shoes on wood	0.9	0.7
Shoes on ice	0.1	0.05
Ice on ice	0.1	0.03
Steel on ice	0.04	0.02

Table 6.1 Approximate Coefficients of Static and Kinetic Friction

Part 2: Physics Diagrams

Practice each of these types of drawings by creating one of each for this scenario:

> *A 30kg hobbit-like creature named Deagol is standing on a raft on the River Anduin. He is fishing with a simple line and hook, and he is trying to pull in a very large fish. Deagol is pulling the fishing line rightward with a force of 200N, but the fish is too strong, and he is slipping leftward toward the edge of the raft. Deagol is accelerating to the left at a rate of 1.2m/s^2. What is the coefficient of friction between Deagol's feet and the raft?*

Cartoon Drawing: This is an informal drawings showing objects, their motions, their surroundings, and anything else you want to add. It provides context for better understanding the System Schema and Free-Body diagrams. You should include accelerations here, if you know them, and you might also want to show net force. You can include some individual forces if you want.

Create a cartoon drawing for Deagol's Situation:

System Schema Diagram: This diagram shows interactions between objects that exert 3rd Law pairs of forces on one another. It is used to identify systems and external forces acting on each system. The rules for system schema diagrams are:

- Write the names of entities/objects that are interacting (i.e. exerting force on one another), and circle each of them. **Leave out air unless drag is specifically mentioned**. <u>If you know the system you want to analyze, you can leave out an object that does not interact with that system.</u> In physics, a "system" is whatever part of the Universe you choose to examine.
- For each force of interaction between objects, connect the objects with a line. Label the line with the name of the force. Use solid lines for contact forces (e.g. Normal force) and dotted or dashed lines for non-contact forces (e.g. gravity, electric force, or magnetism).
- Keep in mind that some entities may interact with multiple forces, so they should be connected with multiple lines.
- If you included objects that are not part of the system you are going to analyze, circle the System you are choosing to analyze with a dotted, dashed, or wavy line – something different than the other circles.

In the space on the right, create a System Schema based on the cartoon. Deagol is the system we are analyzing.

Free-Body Diagram: This is a simple diagram showing the external forces acting on an object (or system). This diagram shows the individual forces that can be added together to give the net force, but it does not include net force.

- Use a box or a circle (with mass inside, when known) to represent the center of mass.
- Show all individual external forces (not net-force, and not internal forces – that do not cross the system boundary in the system schema)
- Draw force vectors as arrows with tails starting at the box and heads pointing outward.
- Label each force vector with the abbreviated name of the force and its magnitude (if known) with correct units.

In the space on the right, us the System Schema to create a Free-Body Diagram showing all of the forces acting on the system of Deagol. Include only forces whose lines crosses the system boundary.

Solve the problem: Use Newton's Laws to fill in the missing parts of the Free-Body Diagram. Write the two different equations for net force and set them equal. Then use the kinetic friction formula to find the coefficient of friction between Deagol's feet and the raft.

Practice Problems – Diagrams With Friction:

1. Someone is pushing a 7kg box leftward across the floor by applying a leftward push of 90N. In front of the 7kg box (to its left) is 10kg box that is being pushed leftward by the 7kg box. The floor is level. The μ_k of both boxes against the floor is 0.6, and both boxes are sliding leftward at the same rate.

   a. Draw a cartoon of this situation in the space to the upper right.

   b. Draw a System Schema for this scenario. Let the two boxes together be the system.

   b. Draw a free-body diagram for the system of the two boxes

   c. Write two equations for the net force acting on the boxes and solve for their acceleration.

   d. Draw a free-body diagram for the system of the 7kg box. [Hint: reconsider the system schema, with only the 7kg box circled as the system.]

2. Two people are playing tug-of-war on a level surface with a massless rope. The person on our right has a mass of 80kg, and their gym shoes have a coefficient of kinetic friction of 0.7 with the floor. The person on our left has a mass of 105kg, but they are barefoot, with a current μ_k =0.5. All of their feet are slipping.

a. Draw a cartoon showing the context of this problem in the space to the upper right.

b. Draw a System Schema for this scenario. Let the two contestants + massless rope be the system.

b. Draw a free-body diagram for the system of the two contestants. Find and include the magnitudes of all of the individual external forces.

d. Find the acceleration of this system (the two contestants and the massless rope)

3. A standup paddleboarder is traveling rightward across a lake. The paddleboard has just run into a large mat of aquatic vegetation (weeds) which is causing both the paddleboard and the paddleboarder to slow down (current acceleration = 0.8m/s^2 **to the left**). In an effort to power through the weeds, the paddleboarder is pulling their paddle leftward with a force of 100N. Their feet are not slipping on the paddleboard. The mass of the paddleboarder is 65kg, and the mass of the paddleboard is 35kg. The mass of the paddle is unknown.

a. Draw a cartoon showing the context of this problem in the space below.

b. Draw a system schema for this situation. Let the system be the paddleboarder only.

c. Draw a free-body diagram for the paddleboarder. Use Newton's Laws to find and include the magnitudes of all of the individual external forces.

d. Write an inequality describing the possible magnitudes of μ_s between the paddleboarder and the paddleboard?

Basic Practice Problems (no diagrams *required* – but they're a good idea)

1. Someone slides a 20kg rock across a horizontal floor. If the person does this by applying a 150N horizontal force, and the rock accelerates at $3.5 m/s^2$, what is the coefficient of friction between the desk and the floor?

2. If the coefficient of kinetic friction between a 35-kg crate and the floor is 0.30…
   a. What horizontal force is required to push the crate at a steady speed across the floor?

   b. What horizontal force is required if μ_k is zero?

3. A force of 48.0 N is required to start a 5.0-kg box moving across a horizontal concrete floor.
   a. What is the coefficient of static friction between the box and the floor?

   b. If the 48.0-N force continues, the box accelerates at $0.70\ m/s^2$. What is the coefficient of kinetic friction?

Practice Problems with Friction and Kinematics

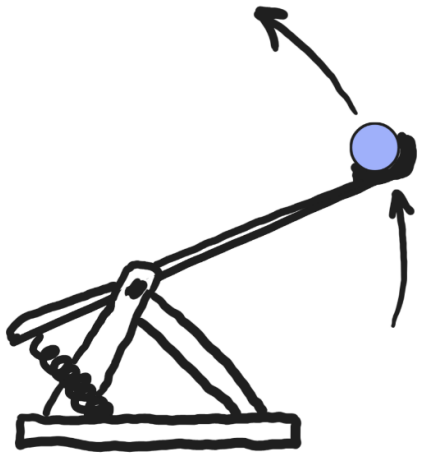
5. Drag-race tires in contact with an asphalt surface have a very high coefficient of static friction. Assuming a constant acceleration and no slipping of tires, estimate the coefficient of static friction needed for a drag racer to travel 1,000m in a time of 12s, starting from rest.

6. A box is given a push so that it slides across the floor. How far will it go, given that the coefficient of kinetic friction is 0.20 and the push imparts an initial speed of $4.0\,\mathrm{m/s}$?

7. Some runners are racing on an extremely slippery floor ($\mu_s = 0.015$, $\mu_k = 0.005$). Starting from rest, what is the shortest amount of time in which one of the runners can run a distance of 10m?

Part 2: Centripetal Acceleration and Gravity

Centripetal Acceleration: An object traveling in an arc of a circle at a constant speed is accelerating toward the center of the circle. This acceleration is called centripetal acceleration (a_c). Centripetal means "toward the center." The magnitude of centripetal acceleration is $a_c = \frac{v^2}{r}$, where v is the speed of the object and r is the radius of the circular arc through which it is traveling.



An object that is following an arc can also have tangential acceleration (i.e. it can be speeding up as well as circling), but in this unit, speed will be constant.

The projectile in the catapult is undergoing both centripetal acceleration and tangential acceleration.

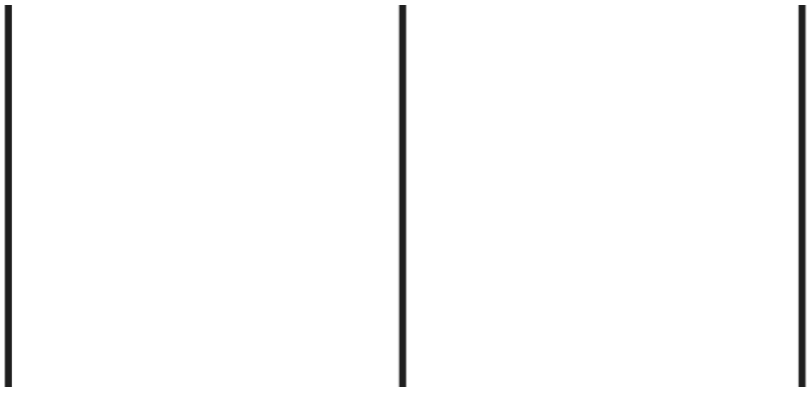
- Show the direction of both kinds of acceleration.
- Make a note regarding the acceleration we will **not** be dealing with in this unit.

When an object is traveling in a circle at a constant speed, the net force acting on the object is the centripetal force.

During "uniform circular motion", **centripetal Force = ΣF =**

Of the five forces we have dealt with, four of them can provide this centripetal force. Draw a diagram for each of them showing how this could work.

Which force won't work to provide consistent centripetal force?



Simulated Gravity: In this unit, we will be discussing simulating the sensation of gravity – mostly in relation to the g's felt during rotational motion. The force most responsible for the sensation of gravity is the _____. Right now, that force is equal to our _____. In a rotating space station far from Earth, we would not have weight, but we would still feel like we have weight due to the _____ exerted on us by the floor.

Problems:

1. (horizontal circle -- friction) A 500kg car drives in a circle with a radius of 20m, maintaining a constant speed of 20m/s. The driving surface is flat and horizontal.

   a. In the upper right, draw a top view cartoon of this situation. Include the car's acceleration and net force.

   b. Draw a system schema

   c. Draw a free-body diagram of the car. Perform any necessary calculations to find all force magnitudes.

   d. Assuming that the car's tires are not slipping, write an inequality for the magnitude of μ_s between the tires and the road.

2. A 60kg teenager is riding a roller coaster that is going through several circular "loop-the-loops." She is currently traveling in a uniform circular path with a radius of 4m, and her speed is constant at 7m/s. At this moment, she is upside-down at the top of the loop, sitting on a bathroom scale that measures the normal force that she experiences. Let's assume that the only thing she is touching is the seat.

a. Draw a cartoon

b. Draw a system schema for the system of the teenager.

c. Draw a free-body diagram for the teenager at the top of the loop. Use Newton's Laws to find the values of all of the individual forces (by writing two equations for net force and setting them equal).

d. Draw a cartoon for the moment when she passes through the bottom of the loop.

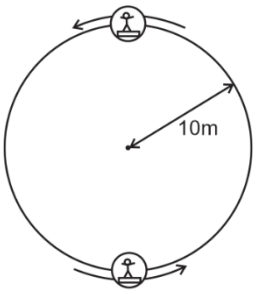
e. Draw a free-body diagram for the teenager at the bottom of the loop. Calculate all forces.

3. (similar to #1)A typical indoor track has turns with a radius of 20m. A runner running a 400m split of 53 seconds has an average speed of approximately 7.55m/s. If the track were flat, and spikes were not allowed, what force of friction would be required in order for a 68kg runner to make the turns at this speed? What value of μ (between shoes and track) would be necessary?

4. (similar to #2) A 1,000kg car is approaching a "loop-the-loop" with a radius of 15m. What speed does the car need to maintain so that the g's experienced the driver approach zero at the top? At this speed, what normal force does the car experience when it is at the bottom of the loop? How many g's are experienced at the bottom?



5. (sort of like #2, but at the top, the normal force is pushing the child in a different direction). A child weighing 200N is standing on a bathroom scale inside a Ferris Wheel that is rotating at a constant rate. If the radius of the circles made by the child is 10m, and the scale reads 100N at the top, what is the child's speed? What does the scale read whe n the child is at the bottom?



Newton's Law of Universal Gravitation:

$\boldsymbol{F_{gravity} = G\left(\frac{m_1 m_2}{r^2}\right)}$ —or— $\boldsymbol{G\left(\frac{Mm}{r^2}\right)}$, where **G** is the gravitational constant (an empirically measured quantity), $\mathbf{m_1}$ and $\mathbf{m_2}$ are two different masses, and **r** is the distance between their centers of mass. When one mass orbits the other, **r** is also referred to as the "orbital radius." *[Often, M is used for a planetary mass, and m is used for its satellite.]*

$\mathbf{G = 6.67x10^{-11}\frac{Nm^2}{kg^2}}$

Altitude: the distance from an object to the surface of the Earth
Altitude + Earth's Radius = orbital radius

6. Calculate the force of gravity between a 100kg student and a 60kg student whose centers of mass are 1.7m apart.

Combining Circular Motion and The Law of Gravitation:

7. Find the value of **g** at Earth's surface. Earth's mass is ($5.972x10^{24}$kg) and its average radius ($6.371x10^{6}$m). **Solve this problem algebraically before plugging in the values.**

8. A satellite is orbiting the a planet at a constant velocity and a constant orbital radius of **r**. Derive a formula for the velocity of the satellite by following these steps.

a. Draw a cartoon in the upper right.

b. Draw a system schema

c. Create a free-body diagram for the satellite.

d. Write two equations for net force in this uniform circular situation. Set them equal and solve for the satellite's velocity in terms of the Earth's mass, the orbital radius, and G.

More Circular Motion Practice:

Helpful Information:

$G = 6.67 \times 10^{-11}\ Nm^2/kg^2$ $M_{Earth} = 5.97 \times 10^{24}\ kg$ $M_{Moon} = 7.35 \times 10^{22}\ kg$ Earth Radius $= 6.378 \times 10^{6}\ m$
Earth Orbital Radius (around the Sun) $= 1AU = 1.50 \times 10^{11}\ m$ Moon Radius $= 1.74 \times 10^{6} m$

1. A 0.2kg ball on a string is swinging in vertical circles with a radius of 0.3m. The ball's speed is constant at 4m/s.

   a. Where in the ball's path is string tension highest?

   b. What is the string tension at that point?

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2. A rock is orbiting a planet in a stable, circular orbit with a constant speed of 800m/s. The rock's orbital radius is 30,000m. What is the mass of the planet that is being orbited?

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3. What is the force of gravitational attraction between the Earth and an astronaut orbiting the Earth at an orbital radius of 3.5×10^{7} m? The astronaut's mass is 65kg.

4. On a spacecraft traveling at a constant speed to planet X, "artificial gravity" is preparing the astronauts for the much *stronger* gravity of the new planet. The spacecraft creates this sensation of gravity by rotating, causing each astronaut to move in a circle at a constant speed of 15m/s (for simplicity, assume the astronauts stand still the whole time). One particular astronaut, who weighs 700N on Earth, experiences a sensation of weight equal to 1,200N on the spacecraft.

   a. Draw a diagram showing the following: the astronaut, the space station, and the individual force(s) acting on the astronaut.

   b. What is the net force acting on the astronaut in your diagram? Give both magnitude and direction.

      Magnitude of Net Force = _____

      Direction of Net force: _____

   c. Calculate the radius of the astronaut's rotations.

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5. The people of Earth have decided that gravity is too strong. We're too heavy, and we're tired of putting up with $g=9.8m/s^2$. We want to lose some weight by reducing the value of **g** at Earth's surface to a more tolerable $8m/s^2$. How could we do this? Describe the value(s) you would have to change – and what you would have to change those value(s) to -- in order to adjust **g** in this way.