L-9 Conservation of Energy, Friction and Circular Motion

- Kinetic energy, potential energy and conservation of energy
- What is friction and what determines how big it is?
- Friction is what keeps our cars moving
- What keeps us moving in circles?
- Centripetal vs. centrifugal force

Kinetic energy

- If something moves in any way, it has kinetic energy
- Kinetic energy (KE) is energy of motion
- If I drive my car into a tree, the kinetic energy of the car can do work on the tree – it can knock it over

\[ KE = \frac{1}{2} m v^2 \]

KE does not depend on which direction object goes

Potential energy

- If I raise an object to some height (h) it also has energy – potential energy
- If I let the object fall it can do work
- We call this Gravitational Potential Energy

\[ \text{GPE} = m \times g \times h = m \times g \times h \]

m in kg, g = 10 m/s^2, h in m, GPE in Joules (J)

- The higher I lift the object the more potential energy it has
- Example: pile driver

Conservation of energy

- If something has energy it doesn’t lose it
- It may change from one form to another (potential to kinetic and back)
- \[ KE + PE = \text{constant} \]
- Example – roller coaster
- When we do work in lifting the object, the work is stored as potential energy.

Amusement park physics

- The roller coaster is an excellent example of the conversion of energy from one form into another
- Work must first be done in lifting the cars to the top of the first hill.
- The work is stored as gravitational potential energy
- You are then on your way!

Up and down the track

If friction is not too big the ball will get up to the same height on the right side.
Loop-the-loop

Here friction works to our advantage. Without it the ball slides rather than rolls.

**A ball won't roll without friction!**

The ball must start at a height $h$, at least $2\frac{1}{2}$ times $R$ to make it through the loop.

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**What is friction?**

- Friction is a force that acts between two surfaces that are in contact
- It always acts to oppose motion
- It is different depending on whether or there is motion or not.
- It is actually a force that occurs at the microscopic level.

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**A closer look at friction**

At the microscopic level even two smooth surfaces look bumpy → this is what produces friction.

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**Static friction**

If we push on a block and it doesn't move then the force we exert is less than the friction force.

$$\text{push, } P \quad \text{friction, } f$$

This is the static friction force at work.

If I push a little harder, the block may still not move → the friction force can have any value up to some maximum value.

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**Kinetic friction**

- If I keep increasing the pushing force, at some point the block moves → this occurs when the push $P$ exceeds the maximum static friction force.
- When the block is moving it experiences a smaller friction force called the kinetic friction force.
- It is a common experience that it takes more force to get something moving than to keep it moving.

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Homer discovers that kinetic friction is less than static friction!
Measuring friction forces

At some point as the angle if the plane is increased the block will start slipping. At this point, the friction force and gravity are equal.

Going in circles

Bart swings the tennis ball around his head in a circle. The ball is accelerating, what force makes it accelerate? *The tension in the string!*

Uniform circular motion

The speed stays constant, but the direction changes. The acceleration in this case is called **centripetal** acceleration.

Centripetal acceleration, $a_C$

The acceleration points toward the center of the circle.

Magnitude of centripetal acceleration

- The centripetal acceleration depends on two factors $\rightarrow$ the speed with which you take the turn and how tight the turn is
- More acceleration is required with a higher speed turn
- More acceleration is required with a tighter turn $\rightarrow$ smaller radius of curvature
Wide turns and tight turns

for the same speed, the tighter turn requires more acceleration

Centripetal acceleration

- centripetal acceleration
  \[ a_c = \frac{v^2}{R} \]
- for some turns, the "safe" speed is posted
- a force is needed to produce this centripetal acceleration

Centripetal force

- where does this force come from?

Ball on a string

The tension in the string provides the necessary centripetal force to keep the ball going in a circle.

Path of ball if the string breaks

Example

- What is the tension in a string used to twirl a 0.3 kg ball at a speed of 2 m/s in a circle of 1 meter radius?
- Force = mass x acceleration \[ (\text{m} \times a_C) \]
- acceleration \[ a_C = \frac{v^2}{R} = \frac{(2 \text{ m/s})^2}{1 \text{ m}} = 4 \text{ m/s}^2 \]
- force = \[ m \times a_C = 0.3 \times 4 = 1.2 \text{ N} \]
- If the string is not strong enough to handle this tension it will break and the ball goes off in a straight line.

Negotiating a flat (level) turn

- The centripetal force is provided by the friction force between the road and tires.
- this force is reduced if the road is wet or icy

Banked Turns

31 degree bank

Velodrome
Banked turns

- Since the road is banked (not horizontal) the force of the road on the box is not vertical
- Part of the force on the box from the road points toward the center of the circle
- This provides the centripetal force
- No friction is necessary to keep the box in the circle

What’s this Centrifugal force ? ?

- The red object will make the turn only if there is enough friction on it
- otherwise it goes straight
- the apparent outward force is called the centrifugal force
- it is NOT A REAL force!
- an object will not move in a circle until something makes it!

Silly Silo (Rotor)

- Friction between Bart and wall
- The inward wall force keeps Bart in the circle.
- Friction keeps him from falling down.

Next time

- What causes an object to rotate?
- Why is a bicycle stable when it is moving but not when it is at rest?
- What makes an object tip over?

Centripetal force and acceleration

- centripetal acceleration
- magnitude \( a_c = \frac{v^2}{R} \)
- in the direction toward the center of the circle
- since \( F = ma \), some force is necessary to produce this centripetal acceleration,
- we call this a centripetal force
  \( \Rightarrow \) we must identify this in each situation