Key Questions Unit 1

Lesson 1 - Relative Motion

1. A ladybug with a velocity of 10.0 mm/s [W] crawls on a chair that is being pulled [50o N of W] at 40.0 mm/s. What is the velocity of the ladybug, relative to the ground?

Solution

<u>Given:</u> Let 'L' represent the ladybug, let 'C' represent the chair and 'G' represent the ground

$$\overrightarrow{V_{LC}} = 10.0 mm/s[W]$$

$$\overrightarrow{V_{CG}} = 40.0 mm/s\text{[N50°W]}$$

Required: $\overrightarrow{V_{LG}}$

<u>Analysis and Solution:</u> Let north and west be positive

$$\overrightarrow{V_{LG}} = \overrightarrow{V_{LC}} + \overrightarrow{V_{CG}}$$

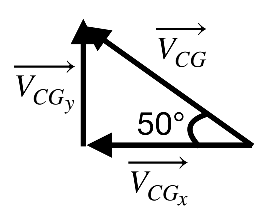
$$\overrightarrow{V_{LG}} = 10.0 mm/s[W] + 40.0 mm/s\text{[N50°W]}$$

X- components and Y-components of the vectors

Components of $\overrightarrow{V_{LC}}$:

$$\overrightarrow{V_{LC_x}} = 10.0 mm/s$$

$$\overrightarrow{V_{LC_y}} = 0.0 mm/s$$



Components of $\overrightarrow{V_{CG}}$:

$$\overrightarrow{V_{CG_x}} = (\overrightarrow{V_{CG}})cos50°$$

$$\overrightarrow{V_{CG_x}} = (40.0 mm/s)cos50°$$

$$\overrightarrow{V_{CG_x}} = 25.7mm/s$$

$$\overrightarrow{V_{CG_y}} = \overrightarrow{V_{CG}} sin 50°$$

$$\overrightarrow{V_{CG_y}} = (40.0mm/s) sin 50°$$

$$\overrightarrow{V_{CG_y}} = (40.0mm/s) sin 50°$$

$$\overrightarrow{V_{CG_y}} = 30.6mm/s$$

Resultant x-component:

$$\overrightarrow{V_{LG_x}} = \overrightarrow{V_{LC_x}} + \overrightarrow{V_{CG_x}}$$

$$\overrightarrow{V_{LG_x}} = 10.0mm/s + 25.7mm/s$$

$$\overrightarrow{V_{LG_x}} = 35.7mm/s$$

Resultant y-component:

$$\overrightarrow{V_{LG_y}} = \overrightarrow{V_{LC_y}} + \overrightarrow{V_{CG_y}}$$

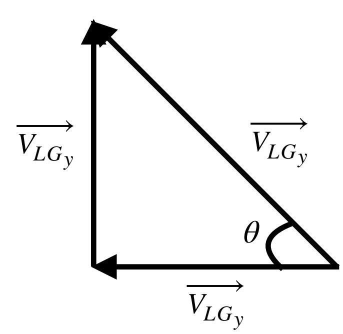
$$\overrightarrow{V_{LC_y}} = (0mm/s) + (30.6mm/s)$$

$$\overrightarrow{V_{LC_y}} = 30.6mm/s$$

Resultant Vector:

$$\overrightarrow{V_{LG}}^2 = \overrightarrow{V_{LGx}}^2 + \overrightarrow{V_{LG_y}}^2$$

$$\overrightarrow{V_{LG}} = \sqrt{\overrightarrow{V_{LGx}}^2 + \overrightarrow{V_{LG_y}}^2}$$



$$\overrightarrow{V_{LG}} = 47.0mm/s$$

$$\tan\theta = \frac{opposite}{adjacent}$$

$$\tan\theta = \frac{\overrightarrow{V_{LG_y}}}{\overrightarrow{V_{LG_x}}}$$

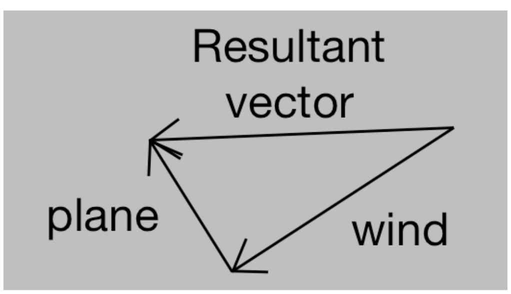
$$\tan\theta = \frac{30.6mm/s}{35.7mm/s}$$

$$\theta = \tan^{-1}\left(\frac{30.6mm/s}{35.7mm/s}\right)$$

$$\theta = 41^{\circ}$$

Therefore, the velocity of the ladybug relative to the ground is 47.0mm/s{W41N]

2. An airplane is flying to a city due west from its current location. If there is a slight wind blowing to the southwest, in what direction must the plane head (that is, in what direction must it point)? Explain your answer using a diagram



Solution:

The plane would have to travel in a direction to counter the wind to reach its destination towards the west. Without the speeds of the wind and the plane being known, the exact angle can not be solved for. However, to counter the southwest wind, the plane must travel northwest to arrive at its destination. This can be seen in a diagram as to obtain a resultant vector which is directed to the west, a northwest vector must be added to the southwest vector of the wind.

3. Do research to find out how relative velocity is related to the direction in which rockets are launched to send them into space. Explain the benefits (to *society and/or the environment) of using a specific direction for launching rockets.*

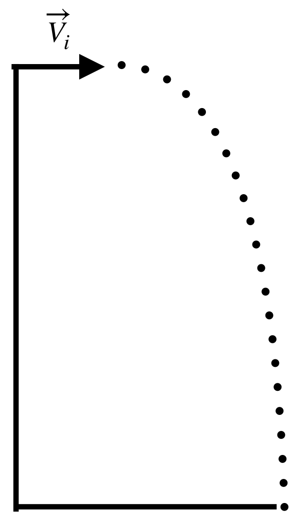
Solution:

Rockets launched are launched at a relative velocity to the earth's rotation. The earth rotates west to east around its axis at a velocity of approximately 1600 km/h at its equator. The rotation of the earth gives the rocket an initial velocity towards to east. If it were to travel in the opposite direction, the rocket would have to overcome its initial momentum towards the east, then generate momentum towards the west. This would cause the launch to take up many more resources than necessary. Rockets are also shot to as close proximity as possible to the equator, as they can take greater advantage of the earth's rotational velocity. This way, rockets can consume less fuel in order to reach their necessary velocity. This leads to less CO2 being emitted into the atmosphere which would cause less pollution. Also, the need for less fuel reduces the cost of the launch, allowing those resources to be used in other areas for the benefit of society.

4.

Solution:

Let [down] be positive y-direction and let [forward] be the positive x-direction



Vertical:

$$\Delta dy = 1.17m$$
$$a = 9.81$$

Horizontal:

$$\Delta d_x = 0.63m$$

$$\Delta t = ?$$

<u>Solving for time:</u>

$$\Delta d_y = \frac{1}{2}at^2$$

$$\Delta t = \sqrt{\frac{2\Delta d_y}{a}}$$

$$\Delta t = \sqrt{\frac{2 \times (1.17m)}{9.81m/s^2}}$$

$$\Delta t = 0.49s$$

<u>Solving for $\vec{V_x}$</u>

$$\vec{V_x} = \frac{\Delta d}{\Delta t}$$

$$\vec{V_x} = \frac{0.63m}{49s}$$

$$\vec{V_x} = 1.29m/s$$

$$\therefore \vec{V_i} = 1.29m/s$$

The initial velocity of the object was 1.29m/s

Possible sources of error:

- Error in reading measurements due to observations being made at an angle, known as a parallax error.
- The firing mechanism of the tape varied in applied force, thus making the initial velocity inconsistent.

Safety precautions taken:

- Removed all fragile objects from the firing area.
- Made sure no one was in the way of the projectile.

Conclusion

When projecting a roll of tape from a height of 1.17m, the average horizontal range was measured to be 0.63m and the magnitude of the initial velocity was calculated to be 1.29m/s.

5. A projectile is launched so that its point of launch is lower than its landing point.

a) When is the vertical velocity at a maximum?

The vertical velocity is at its maximum just before landing

b) When is the horizontal velocity at a maximum?

The horizontal velocity remains constant throughout the motion.

c) When is the vertical velocity at a minimum?

The vertical velocity is at a minimum when it reaches its maximum height where the velocity is 0m/s as the object changes direction

d) What is the acceleration of the object at the very top of its path? Explain.

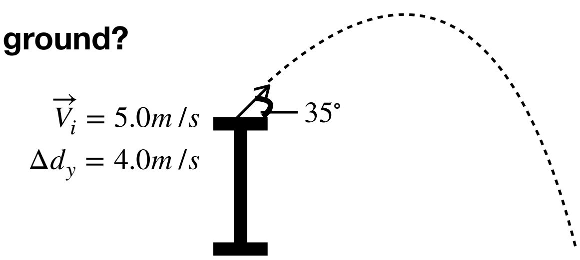
The acceleration remains constant (9.8m/s). This is because from when the object leaves the launching point till it hits the ground, the acceleration is the force of gravity as it is the only force acting on the object ignoring air resistance.

e) Which will take longer: the upward motion or the downward motion?

The upward motion will take longer, as the object is accelerating downwards.

6. A child sitting in a tree throws his apple core from where he is perched (4.0 m high) with a velocity of 5.0 m/s [35° above the horizontal], and it hits the ground right next to his friend.

a) How long does it take for the apple core to hit the ground?



Required:

- Time of flight

- Horizontal displacement

- Final velocity

Analysis and Solution:

Let [down] be the positive y-direction

Let [forward] be the positive x-direction

Given:

$$\vec{V}_i = 5.0m/s$$
$$a = 9.81m/s^2$$
$$\Delta d = 4.0m$$
$$\theta = 35^\circ$$
$$\Delta t = ?$$

Vertical:

$$\overrightarrow{V_{i_y}} = \overrightarrow{V_i} \sin\theta$$

$$\overrightarrow{V_{i_y}} = (5.0m/s) \times (\sin 35°)$$

$$\overrightarrow{V_{i_y}} = 2.87m/s$$

$$\Delta d = \overrightarrow{V_{i_y}}\Delta t + \frac{1}{2}a\Delta t^2$$

$$4.0m = (2.87m/s)\,\Delta t + \frac{1}{2}\left(9.81m/s^2\right)\,\Delta t^2$$

$$\left(4.9m/s^2\right)\,\Delta t^2 - (2.87m/s)\,\Delta t - 4.0m = 0$$

Quadratic Formula

$$\Delta t = \frac{-(-2.87) \pm \sqrt{(-2.87)^2 - 4 \times (4.9) \times (-4.0)}}{2 \times (4.9)}$$

$$\Delta t = \frac{2.87 \pm 9.32}{9.8}$$

$$\Delta t = \frac{2.87 + 9.32}{9.8}$$

$$\Delta t = 1.2$$

$$\Delta t = \frac{2.87 - 9.32}{9.8}$$

$$\Delta t = -0.66$$

Since time cannot be negative, $\Delta t = 1.2$s

It took the apple core 1.2 seconds to hit the ground

b) How far from the base of the tree will the apple core land?

$$\overrightarrow{V_{i_x}} = \frac{\Delta d_x}{\Delta t}$$

$$\Delta d_x = \overrightarrow{V_{i_x}}\Delta t$$

$$\overrightarrow{V_{i_x}} = V_i \cos\theta$$

$$\overrightarrow{V_{i_x}} = \left(5.0m/s\right) \times \left(\cos 35^\circ\right)$$

$$\overrightarrow{V_{i_x}} = 4.1m/s$$

$$\Delta d_x = (4.1m/s) \times (1.2s)$$

$$\Delta d_x = 4.9m$$

The apple will land 4.9m away from the base of the tree

c) What is the velocity of the apple core on impact?

Vertical

$$a = 9.81m/s^2$$
$$\Delta dy = 4.0m$$
$$\overrightarrow{V_{i_y}} = -2.87m/s$$
$$\overrightarrow{V_{2_y}} = ?$$

Horizontal

$$\Delta d = 2.7m$$
$$\overrightarrow{V_{i_x}} = 4.9m/s$$
$$\overrightarrow{V_{2_x}} = 4.9m/s$$

$$\left(\overrightarrow{V_{2_y}}\right)^2 = \left(\overrightarrow{V_{i_y}}\right)^2 + 2a\Delta d_y$$

$$\left(\overrightarrow{V_{2_y}}\right)^2 = (-2.87m/s)^2 + 2 \times \left(9.81m/s^2\right) \times (4.0m)$$

$$\overrightarrow{V_{2_y}} = \sqrt{86.8369}$$

$$\overrightarrow{V_{2_y}} = 9.3m/s$$

$$\overrightarrow{V_2} = ?$$

$$\left(\overrightarrow{V_2}\right)^2 = \left(\overrightarrow{V_{2_x}}\right)^2 + \left(\overrightarrow{V_{2y}}\right)^2$$

$$\left(\overrightarrow{V_2}\right)^2 = (4.9m/s)^2 + (9.3m/s)^2$$

$$\left(\overrightarrow{V_2}\right)^2 = 110.5$$

$$\overrightarrow{V_2} = \sqrt{110.5}$$

$$\overrightarrow{V_2} = 11m/s$$

$$\theta = ?$$

$$\theta = \tan^{-1}\left(\frac{\overrightarrow{V_{2y}}}{\overrightarrow{V_{2_x}}}\right)$$

$$\theta = \tan^{-1}\left(\frac{9.3m/s}{4.3m/s}\right)$$

$$\theta = 65^\circ$$

The velocity of the core on impact would be 11m/s[65° below horizontal]

7. Describe three ways that understanding projectile motion and relative velocity could help you improve your success in a basketball game.

Three ways that understanding projectile motion and relative velocity could help improve success in a basketball game are:

1. To aim your shot above the basket, as gravity will cause the ball to accelerate downwards the moment it is shot.

2. Pay attention to make the initial velocity of the ball so that the horizontal range is the same distance between the player and the net.

3. The speed at which the ball is released must also be adjusted based on the height of the release point. Knowing the difference in height between the net and the release point will aid the player in determining the amount of time the ball should be in the air before landing in the net.

Lesson 3 - Forces and Motion

8. If an object is in motion, does that mean that the object has a net force in the direction of that motion? Explain.

A net force is needed to cause a change of motion of an object (e.g accelerating, changing direction). "Net force" is a term used because there could be multiple forces acting on a certain object to see if the forces are unbalanced or cancel out. If not, what is left over causes the object to accelerate, and whichever direction the object accelerates to is the direction of the net force.

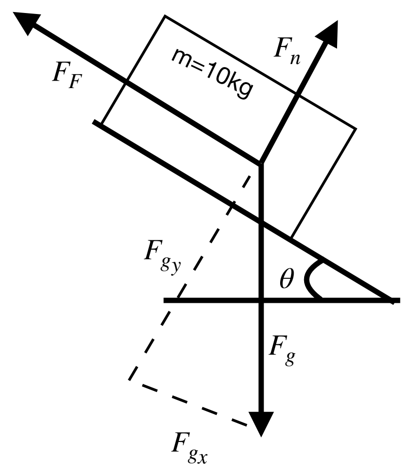
9. At a construction site, a small crane is raising two boxes of nails on a plank to the roof. One box has already been opened and is half full, while the other box is new. The boxes, including the nails, weigh 10 kg and 20 kg, respectively, and are the same size.

a) As the plank tilts towards the heavier box, predict which box of nails will start to slide first. Explain your prediction.

Both will slide at the same time since the force accelerates them down is gravity, which accelerates them at an equal rate. Mass won't matter in the speed at which they slide, only the angle of the plank and the friction.

b) If the coefficient of static friction is 0.4, draw an FBD for each box of nails and use it to calculate the angle at which each box begins to slide.

Box 1

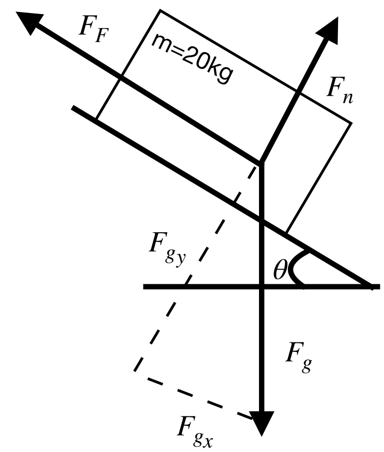


Y-direction:

$$m_1 = 10kg$$
$$g = 9.81m/s^2$$
$$F_{net} = 0.00N$$
$$F_g = ?$$
$$F_g = m_1 \cdot g$$
$$F_g = 10kg \cdot 9.81m/s^2$$
$$F_g = 98.1N$$
$$F_{net_y} = F_n - F_{g_y}$$
$$0 = F_n - 98.1N$$
$$F_n = 98.1N$$

X-direction

$$F_{net_x} = F_{g_x} + F_f$$
$$F_{net_x} = F_g sin\theta + \mu f_n$$
$$F_n = -F_g \cos\theta$$
$$F_{net_x} = F_g \sin\theta + \mu\left(-F_g \cos\theta\right)$$
$$0 = 98N \sin\theta + 0.4 \times (-98N \cos\theta)$$
$$98N \sin\theta = 39.2 \times \cos\theta$$
$$\sin\theta = \frac{39.2 \times \cos\theta}{98N}$$
$$\frac{\sin\theta}{\cos\theta} = 0.40$$
$$\tan\theta = 0.40$$
$$\theta = \tan^{-1}(0.40)$$
$$\theta = 21.8^\circ$$



The angle at which the boxes begin to slide is 21.8°

c) If the coefficient of kinetic friction is 0.3, how fast will the boxes accelerate along the plank, once they start to slide?

$$F_{net_x} = F_g \sin\theta + M\left(-F_g \cos\theta\right)$$
$$0 = 98N \sin\theta + (0.3) \times (-98N \cos\theta)$$
$$sin\theta = \frac{29.4cos\theta}{98N}$$
$$\frac{\sin\theta}{\cos\theta} = 0.3$$
$$\tan\theta = 0.3$$
$$\theta = \tan^{-1}(0 \cdot 3)$$
$$\theta = 16.7^{\circ}$$
$$\mu_k = 0.3$$
$$F_{net} = F_g \sin\theta - F_f$$
$$F_{net} = ma$$
$$ma = F_g \sin\theta - \mu F_n \cos\theta$$

Box 1:

$$a_1 = \frac{F_g \sin\theta - \mu F_n \sin\theta}{m_1}$$
$$= \frac{28.2 - (0.3) \times (-98N) \times \cos 22^{\circ}}{10kg}$$
$$= 5.5m/s^2$$

Since both boxes accelerate at the same rate this applies to both. They would accelerate at a rate of 5.5m/s².

10. Design a simple experiment that you could carry out in your home to

i) determine the coefficient of static friction between an object and a surface.

ii) prove that the coefficient of static friction is dependent only on the surfaces in contact, and is not affected by any change in the mass of your object.

a) Describe your plan. It must include a list of materials, a diagram of the set-up, and an explanation of the steps you would take and the data you would collect.

Materials:

1. Incline plane (adjustable)
2. Two objects of different masses, preferably of the same material so the coefficient of friction is the same
3. Mass measuring scale

Steps:

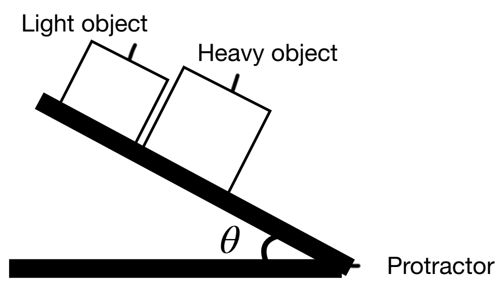
1. Position the incline plane on a level surface
2. Put both heavy and light objects on the plane
3. Lift the plane until both objects start falling. Repeat 4 to 5 times.
4. Collect the following data:
    a. Mass of the heavy object
    b. Mass of the lighter object
    c. Average angle at which both start to slide

b) Explain how you would analyze the collected data to determine the coefficient of static friction and prove that it is unaffected by any change in the mass of your object.

By using the collected data and solving for the coefficient of friction for both objects, it can be seen that it remains the same regardless of the difference in mass of the objects.

Experiment	Angle
Experiment 1	23°
Experiment 2	20°
Experiment 3	21°
Experiment 4	18°
Experiment 4	26°
Average Angle	21.6°

10. Diagram:



Solving for the coefficient of friction:

$$F_{net_x} = F_g \sin\theta + \mu\left(-F_g \cos\theta\right)$$

$$F_{net} = 0$$

$$F_g \sin\theta = \mu\left(F_g \cos\theta\right)$$

$$\frac{F_g \sin\theta}{F_g \cos\theta} = \mu$$

$$\tan\theta = \mu$$

$$\tan\left(21.6^\circ\right) = \mu$$

$$\mu = 0.4$$

As shown in the analysis, Fg, the force of gravity, cancels out, which leaves the coefficient of friction independent of the mass of the object.

c) State one possible source of error that you might encounter in this experiment and state the steps you took to minimize or eliminate this source of error.

- The objects could have been of a different material, which would make them have a different coefficient of friction. To eliminate this source of error, the material of the objects where identical, leaving the only difference being their mass.
- Another source of error could have been placing the plane on an uneven surface or errors in calculation.

11.

a) one example in which friction is maximized to aid in transportation

While driving on the road, car tires are made to maximize friction on the road to minimize any chance of slipping. Doing this provides safety for the driver as well as people around them. Car tires are specifically designed to accommodate each condition. The way they are designed is to ensure water or snow goes under the tires while keeping contact with the road which provides traction. Over the years, designs have kept improving, allowing for safer roads.

b) one example in which friction is maximized to aid in transportation

Electromagnetic propulsion is used to minimize friction, and increase speed of long distances. It is commonly used in trains or roller coasters. Friction is minimized by levitating the train off the tracks, limiting the contact between them. It is beneficial is it allows transportation of a greater distance over a shorter length of time.

c) sources:

http://boson.physics.sc.edu/~rjones/phys101/tirefriction.html

https://science.howstuffworks.com/electromagnetic-propulsion.htm

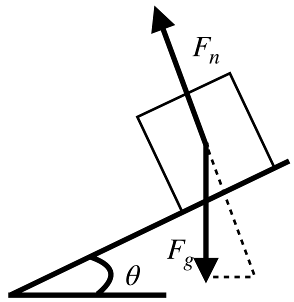
---

Lesson 4 - Circular Motion

12. Does the label “centripetal force” ever appear in an FBD? Explain.

Centripetal force is the same thing as net force, and it is not shown on an FBD. The only forces shown are forces which act upon an object are shown in an FBD.

13. Sometimes, road surfaces have banked curves. Use an FBD to explain how this helps cars to make turns more safely.



If a car turns on a normal road without a bank, all of the force in the turn will be used thus making a stronger force in the centripetal force equation. This increases the chance of the car being pushed out of the turn. A banked road not only works as a barrier, stopping the car from being pushed, but also results in the turning force to be divided into two vectors. This results in less centripetal force being created, allowing for a much safer turn since the force is now distributed into smaller vectors. As shown on the diagram, the normal force acting on the car has a component in the same direction as the centripetal force. The component of the normal force which acts toward the center of the curve acts as a balance.

14. A buss passenger has her laptop sitting on the flat seat beside her as the bus, travelling at 10.0 m/s, goes around a turn with a radius of 25.0 m. What minimum coefficient of static friction is necessary to keep the laptop from sliding?

Given:

$$V = 10.0m/s$$
$$r = 25.0m$$
$$g = 9.8m/s^2$$
$$\mu = \frac{v^2}{gr}$$
$$\mu = \frac{(10m/s)^2}{\left(9.8m/s^2 \cdot 25.0m\right)}$$
$$\mu = 0.41$$

The minimum coefficient of friction necessary to keep the laptop from sliding would be 0.41.

15. Keys with a combined mass of 0.100 kg are attached to a 0.25 m long string and swung in a circle in the vertical plane.

a)

$$m = 0.100kg$$
$$r = 0.25m$$
$$g = 9.8m/s^2$$
$$F_c = F_g$$
$$\frac{mv^2}{r} = mg$$
$$V = \sqrt{gr}$$
$$V = \sqrt{\left(9.8m/s^2\right) \times \left(0.25m\right)}$$
$$V = 1.6m/s$$

b)

$$F_t = F_c + F_g$$
$$F_g = mg$$
$$F_g = 0.100kg \cdot 9.8m/s^2$$
$$F_g = 0.98N$$
$$F_c = \frac{mv^2}{r}$$
$$F_c = \frac{\left(0.100kg\left(1.6m/s\right)^2\right)}{0.25m}$$
$$F_c = 1.024$$
$$F_t = 1.024N + 0.98$$
$$F_t = 2.0N$$

a) What is the lowest speed that the keys can swing and still maintain a circular path?

The lowest speed the keys can swing and still maintain circular motion is 1.6m/s

b) What is the tension in the string at the bottom of the circle?

The tension in the string is 2.0N when the keys are at the bottom of their path.

16. Do research to find out what artificial gravity is and how it is related to centripetal motion. Explain how artificial gravity could be created in a weightless environment and give a reason why we would want to do this. Give at least one source that you used for your research.

Artificial gravity is used in space as well as on Earth. It can be created by the means of different forces, such as centrifugal force and linear acceleration. As it has been theorized, artificial gravity would take form as the inertial reaction to centripetal acceleration which would act on the the intended objects in circular motion. Artificial gravity would be produced by the use of centripetal or linear acceleration which create a pulling sensation towards the floor, similar to gravity. Artificial gravity would be beneficial for astronauts as many of them suffer from SAS (Space Adaptation Syndrome), which can cause disorientation and nausea because of the absence of gravity. Artificial gravity will aid in research as well as space travel.

source:http://www.popularmechanics.com/space/rockets/a8965/why-dont-we-have-artificial-gravity-15425569/