Arvind Borde / PHY 11, Week 5: Circular Motion & Gravitation

Circular Motion

(1) Is an object moving in a circle at fixed speed accelerating? Why?

____

This acceleration is called ______________ and its magnitude is

where v is the (constant) speed and r the radius
1 of the path.

Centripetal acceleration points radially inward.

(2) What is a_C for an object moving at $20\,\mathrm{m/s}$ in a circle of radius $10\,\mathrm{cm}$?

The force that causes a_C is the ______________ ________:

2 pointing inward.

When an object is whirled around on a string

the tension (tautness) in the string provides the centripetal force. The faster an object whirls around the __________ the tension.

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(3) What's the tension, T, if an object of mass $100\,\mathrm{g}$ is whirling around on a string in a circular path of radius $0.75\,\mathrm{m}$ at $5\,\mathrm{m/s}$?

$$T = F_C =$$

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(4) If the speed doubles, will T go up or down? ______

(5) By what factor? ________

(6) If the radius doubles, will T go up or down? ________

(7) By what factor? ________

5

(8) If the string in Q3 can only support a tension of $5\,\mathrm{N}$ before breaking, what is the maximum speed an object can whirled around at? (m, r the same.)

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ADDITIONAL NOTES

There's another "force" associated with circular motion that people refer to as the ______________ __________

That's the "force" you feel pushing you outward as you round a curve.

But it's not an actual force: it's an expression of your inertia.

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As the car rounds the curve, you try to maintain your motion in a straight line (______________), but the car presses against you, to force you to change the direction of your motion.

You press back on the car (______________) because of your inertia, your tendency to resist forces.

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Gravitation

An important example of a centripetal force is the force of gravity acting on objects in orbit (e.g., moon around earth).

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The most immediate experience we have of gravity is that things fall.

If the earth were at the center of the Universe, as was thought, one could attribute the tendency of things to fall as their natural tendency to go to the center of the Universe because of their weight. That was the view of Aristotle, and co. (∼300 BC).

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According to this view, the "heavens" were fixed (apart from the wandering planets) and objects fell because they were trying to get to the center of the Universe.

In the Aristotelian view heavier objects would fall more quickly.

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Galileo spoiled all that in the 1600s by dropping things.

Around the same time it became clear that the "heavens" were more complicated than had been thought: planets had moons that went around them, for example.

The earth was not the center of everything.

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ADDITIONAL NOTES

In the late 1600s, Isaac Newton fixed everything – the shenanigans in the heavens and why things fall to earth by

Newton's Law of Universal Gravitation

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2},$$

$$G = 6.67 \times 10^{-11}\frac{N \cdot m^2}{kg^2}$$

Gravitational constant

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In English:

Every object (mass m_1) attracts every other object (mass m_2) by a force proportional to the product of their masses and inversely proportional to the square of the distance between them.

m_1 •→attractive gravitational force ←○ m_2

$\underbrace{\qquad\qquad\qquad}_{distance = d}$

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Why is this a universal law? Because ________
____

It applies to you and the earth, to a piece of chalk and the earth, to a piece of chalk and another piece of chalk, to the earth and the moon, to the sun and Jupiter, . . .

The law uses "proportionality." What's that?

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If $y = x$ then the quantity y equals x.

If $y = 5x$ then y is ______________ x. We write this as

$$y \propto x$$

This is true whenever $y = kx$ for any fixed k ("__________________").

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In Newton's gravitational law

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2}$$

the quantity G is the proportionality constant.

______________ – same value for any two objects:

$$G = 6.67 \times 10^{-11} \text{N} \cdot \text{m}^2/\text{kg}^2$$

(this is the value when you measure mass in kilograms and distance in meters).

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We also need ________________. If

$$y = k \times \frac{1}{x} = \frac{k}{x}$$

where k is fixed, then y is said to be inversely proportional to x.

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ADDITIONAL NOTES

Assume $k > 0$. If

(9) $y = kx$, as x goes up, y __________

(10) $y = kx$, as x goes down, y __________

(11) $y = \frac{k}{x}$, as x goes up, y __________

(12) $y = \frac{k}{x}$, as x goes down, y __________

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Using Newton's law

$$F_{\text{grav}} = G\frac{m_1 m_2}{d^2}$$

(13) Does the gravitational force go up as the masses go up? __________

(14) Does the gravitational force go up as the distance increases? __________

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We need to be more specific about *how much* the gravitational force goes up and down by.

The gravitational force on an object of mass m due to the earth (mass M_{E}) is

$$F = G\frac{mM_{\text{E}}}{d^2}$$

where d is the distance to the *center of the earth*.

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In each case below, does the gravitational force on m go up or down, and by how much?

(15) m doubles: __________

(16) m triples: __________

(17) m halves: __________

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How the gravitational force depends on distance is *slightly* trickier:

If the distance between the two objects goes up, the force __________.

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In each case below, does the gravitational force on m go up or down, and by how much?

(18) d doubles: __________

(19) d triples: __________

(20) d halves: __________

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ADDITIONAL NOTES

This means that if the distance between two objects doubles, one of their masses would have to go up by a factor of 4 in order to keep the force the same.

This is Newtonian gravity. The theory works spectacularly well, but not perfectly...

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If one of the masses is the earth, with mass M_E, then the gravitational force between it and an object of mass m, is

$$G\frac{mM_E}{d^2}$$

where d is the distance of the mass m to __________ __________________

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That tells you how the force *arises*.

(21) The *effect* of this force is to directly produce
- (a) vomiting?
- (b) velocity?
- (c) acceleration?

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(22) What law governs how much acceleration?

____

Equating the two

$$ma = G\frac{mM_E}{d^2} = m\left[\frac{GM_E}{d^2}\right]$$

Cancel m:

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(23) For $d = R_E = 6.4 \times 10^6$ m, $M_E = 6 \times 10^{24}$ kg, calculate

$$a = \left[\frac{GM_E}{d^2}\right]$$

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ADDITIONAL NOTES

(24) What's the gravitational force between the earth and a $100\,\text{g}$ apple held $1\,\text{m}$ above its surface?

$$F = G\frac{m_{\text{apple}} M_E}{d^2}$$

$M_E = 6 \times 10^{24}$ kg

$m =$

$d =$

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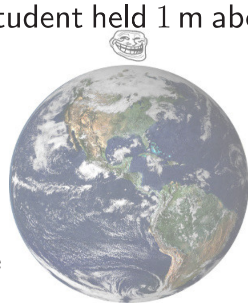
(25) What's the gravitational force between the earth and a $1000\,\text{kg}$ physics student held $1\,\text{m}$ above the surface of the earth?

$$F = G\frac{m_{\text{student}} M_E}{d^2}$$



Now $m_{\text{student}} =$ ______ m_{apple}

So $F_{\text{student}} =$ ______ $F_{\text{apple}} \approx$

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ADDITIONAL NOTES