Spring 2014

PHYS-2010

Lecture 22

Clicker Question

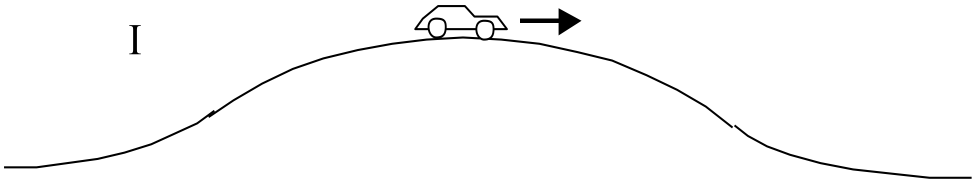
Room Frequency BA

Consider the following two situations:

Situation I: A car on Earth rides over the top of a round hill, with radius of curvature R = 100 m, at constant speed v = 35 mph.

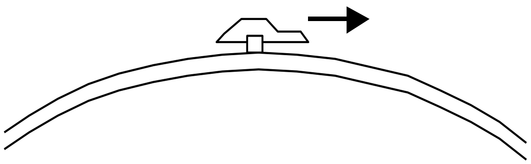
Situation II: A monorail car in intergalactic space (no gravity) moves along a round monorail, with radius of curvature R = 100 m, at constant speed v = 35 mph.

I



Which car experiences larger acceleration?

II



A) Earth car

B) Space car

C) Both cars have the same acceleration.

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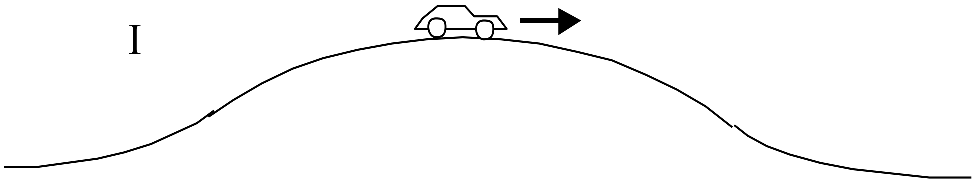

Which car experiences larger acceleration?

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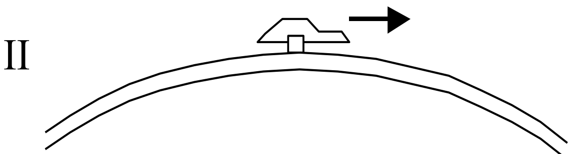

Both objects are moving on a circle of the same radius R at the same speed v. The magnitude of the acceleration is $a = v^2/R$.

Announcements

- Read Giancoli Chapter 5.
- **No Written homework** this week!
- **CAPA # 8** is due next Tuesday.
- **Midterm II** tomorrow, Thursday, March 6, at 7:30 pm.
- **Exam seating:**
  - if your TA is Rosemary Wulf or Andrew Hess, your exam is here, G1B30.
  - if your TA is Jake Fish or Clarissa Briner, your exam is next door, G1B20.
- More details about the exam are on the course website:

http://www.colorado.edu/physics/phys2010/phys2010_sp14/exams.html

Clicker Question

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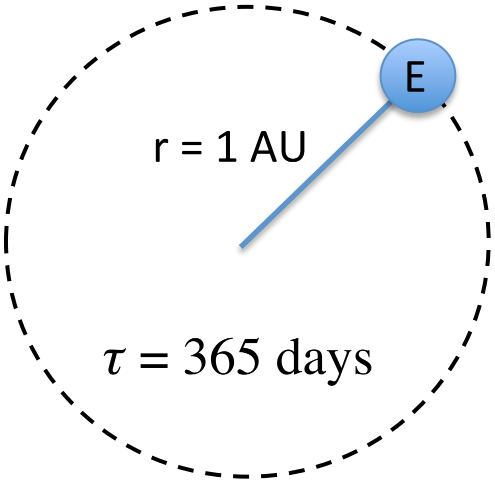
The Earth circles the Sun at an average distance of $1\ AU = 1.5 \times 10^{11}$ m in 1 year.



What's causing the centripetal acceleration?

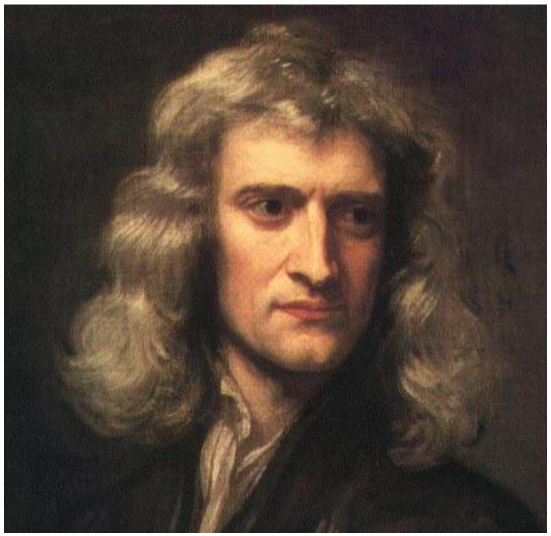
A) The electrostatic force between the Earth and Sun.

B) The tension in the string connecting the Earth to the Sun.

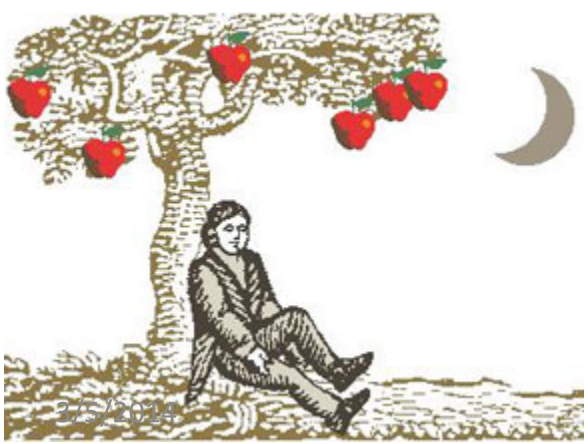
C) The force of gravity between the Earth and the Sun.

D) Depends on the time of day.

Newton’s Law of Universal Gravitation



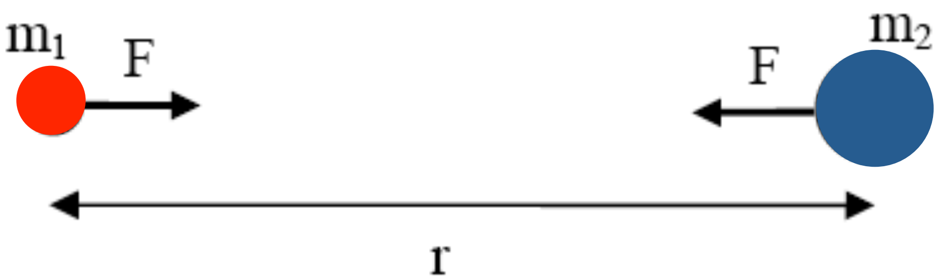
Insight: what keeps the Moon in orbit around the Earth and the Earth in orbit around the Sun is exactly the same thing that causes an “apple to fall from a tree”.



“Every particle in the universe attracts every other particle.”

Newton's Law of Universal Gravitation

"Every particle in the universe attracts every other particle with a force proportional to the product of their masses and inversely proportional to the square of the distance between them. The force points along the line joining the two particles."



$$|\vec{F}|_{gravity} = G\frac{m_1 m_2}{r^2}$$

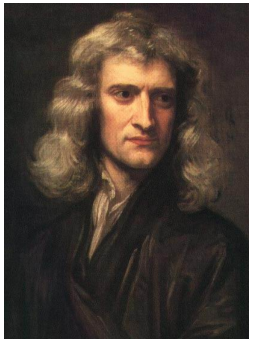
$$G \approx 6.67 \text{ x } 10^{-11} Nm^2 / kg^2$$

Gravitational Constant (Newton's Constant)

Universal Gravitation Verification

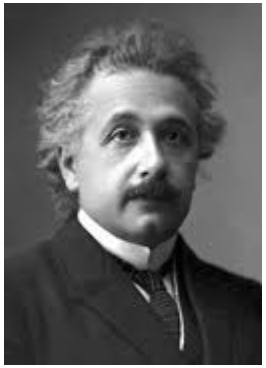
1687: Isaac Newton published Gravity Theory

$$|\vec{F}|_{gravity} = G\frac{m_1 m_2}{r^2}$$



1798: Henry Cavendish confirmed this formula experimentally and measured *G*.

1915: Albert Einstein's General Theory of Relativity explained why gravity behaves this way.



How Strong is Gravity?

m_1 = 70 kg

m_2 = 70 kg

r = 1 meter

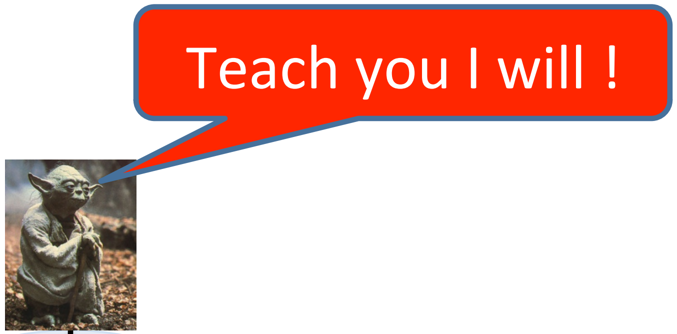
$$|\vec{F}|_{gravity} = G\frac{m_1 m_2}{r^2} = \left(6.67\times10^{-11}\frac{Nm^2}{kg^2}\right)\frac{(70kg)(70kg)}{(1m)^2}$$

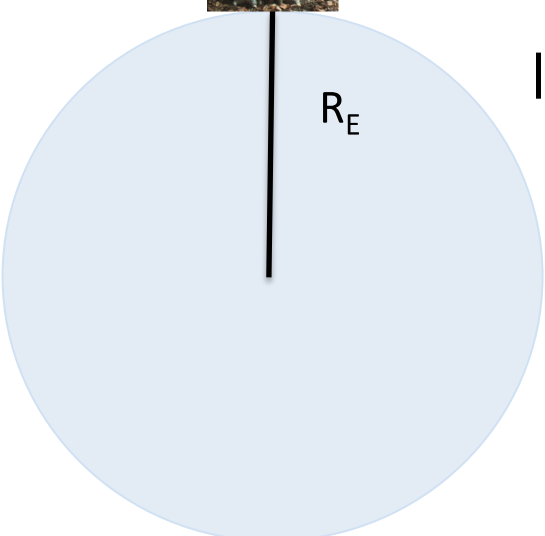
$$|\vec{F}|_{gravity} = 3.3\times10^{-7}\text{ Newtons} = 7.5\times10^{-8}\text{ Pounds}$$

That is about 1/60th the weight of a single hair!

Big *G*, Little *g*

What is the force of gravity exerted by the Earth with mass $\boldsymbol{M_E}$ on a person of mass $\boldsymbol{m}$ on its surface?





$$|\vec{F}|_{gravity} = \frac{GM_E m}{R_E^2}$$

$$|\vec{F}|_{gravity} = \left(6.67\times10^{-11} Nm^2/kg^2\right)\frac{\left(5.98\times10^{24} kg\right)}{\left(6.37\times10^{6} m\right)^2} m$$

$$|\vec{F}|_{gravity} = m\times\boxed{\left(9.81 m/s^2\right)}$$

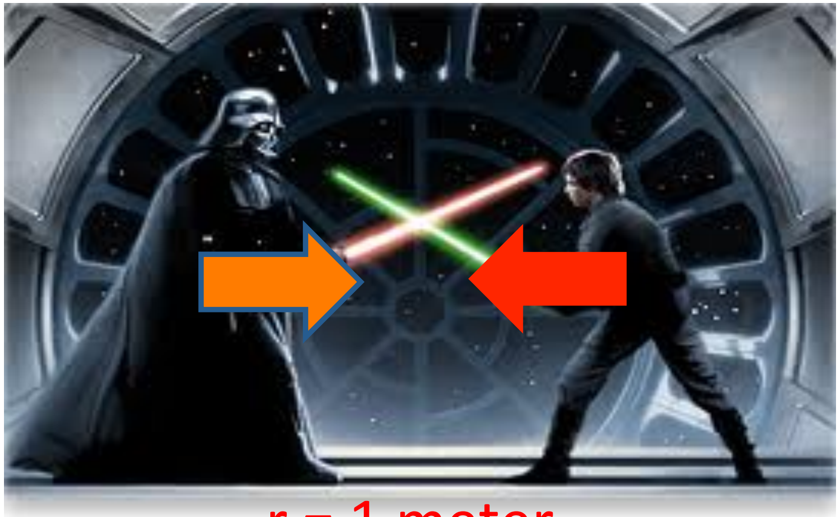
Surprise, surprise !!

$$|\vec{F}|_{gravity} = mg$$

Gravitational force on an object on the surface of the Earth!

Who does the force act on?

m_1 = 70 kg



m_2 = 70 kg

r = 1 meter

$$|\vec{F}|_{gravity} = 3.3\times10^{-7} \text{ Newtons}$$

Answer = Both – *Newton's 3rd law!*

Person #1 exerts a force on Person #2

Person #2 exerts a force on Person #1

Clicker Question

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Yoda is standing on the surface of the planet Dagobah.

Strong is the Force with me!

Dagobah exerts a gravitational force $\mathbf{F}_{\mathbf{Dagobah}}$ on Yoda, and Yoda exerts a gravitational force $\mathbf{F}_{\mathbf{Yoda}}$ on Dagobah.

Which of the following is correct:

A) $F_{Dagobah} > F_{Yoda}$

B) $F_{Dagobah} < F_{Yoda}$

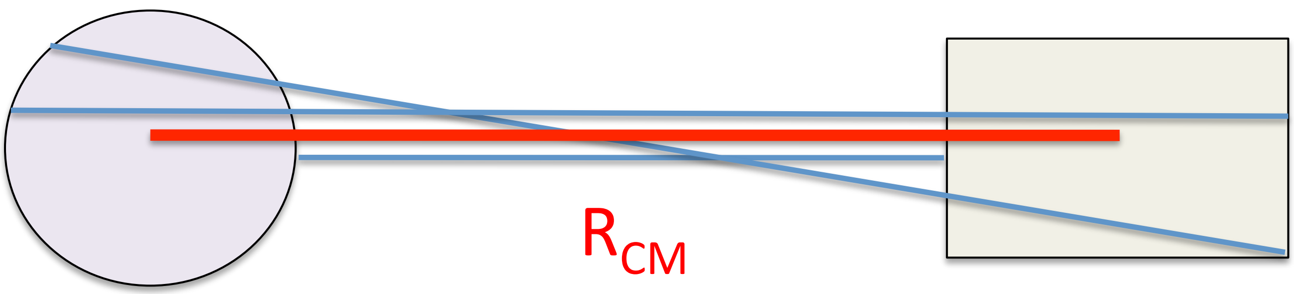
C) $F_{Dagobah} = F_{Yoda}$

D) It's not so simple, we need more information.

Newton's Third Law!

Extended Objects

Objects are extended in space.
Newton's Law of Universal Gravitation is based on computing the distance between two objects,
but which distance?



In fact, every part of object #1 exerts a gravitational attraction on every part of object #2, and vice versa.

When adding all vector components, we treat the force as acting between the "center of mass" of each object.

"Center of mass" for sphere = middle

Clicker Question

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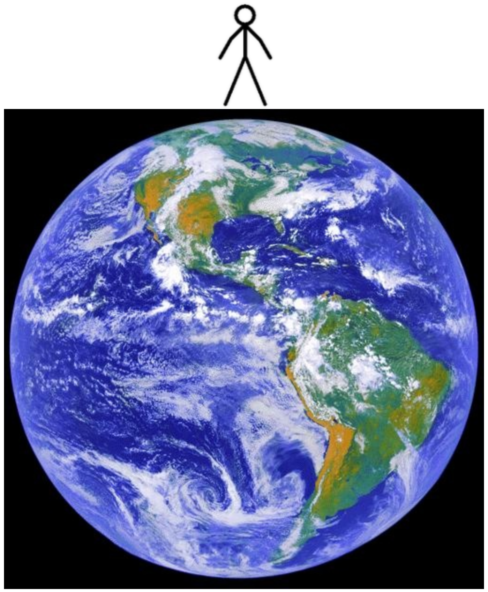
You are on the surface of the Earth, and jump up for a second.

The Earth exerts a gravitational force on you $\mathbf{F}_{\mathbf{earth}}$, and you exert a gravitational force on the Earth $\mathbf{F}_{\mathbf{person}}$.



Which is correct about the accelerations of you and the Earth?

A) $a_{earth} > a_{person}$

B) $a_{earth} < a_{person}$

C) $a_{earth} = a_{person}$

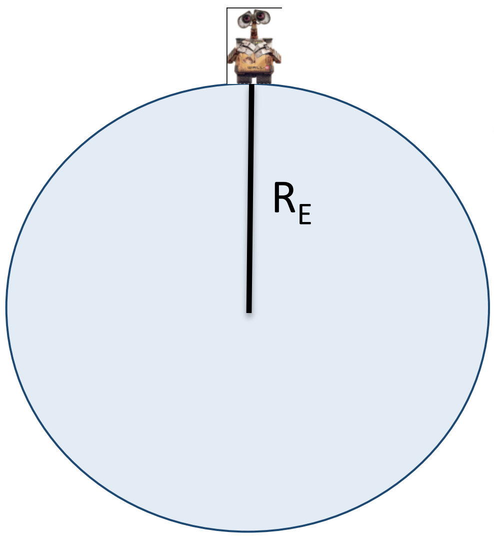
D) It’s not so simple, we need more information.

$$M_E a_E = G\frac{M_E M_p}{r^2} \Rightarrow a_E = G\frac{M_p}{r^2}$$

$$M_p a_p = G\frac{M_E M_p}{r^2} \Rightarrow a_p = G\frac{M_E}{r^2}$$

Weighing the Earth!

Consider the force of gravity exerted by the Earth's mass *M* on a person of mass *m* on its surface:

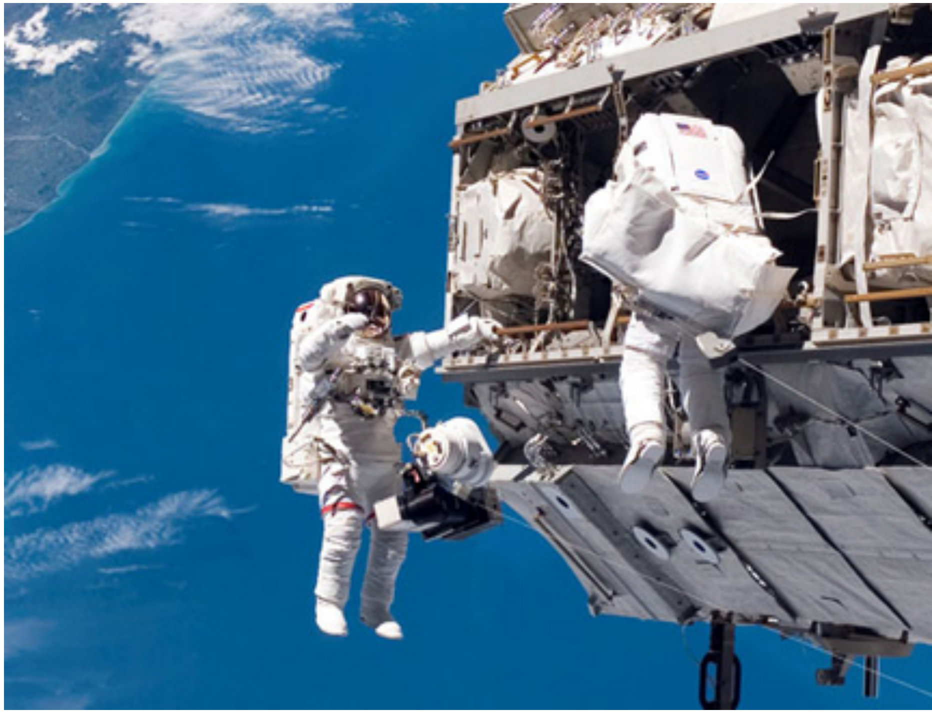


$$\cancel{m}g = F_g = G\frac{\cancel{m}M}{R_E^2} \rightarrow \boxed{g = a_g = G\frac{M}{R_E^2}}$$

We can use this to measure the mass of the Earth!

$$M_E = \frac{gR_E^2}{G} = \frac{9.8\text{m/s}^2(6.37x10^6\text{m})^2}{6.67x10^{-11}\text{Nm}^2/\text{kg}^2} = 5.98\text{x}10^{24}\text{kg}$$

International Space Station (ISS)



Circular orbit with altitude between 278 km and 460 km.

Average speed 27,000 km/hour and 15.7 orbits per day.

Astronauts experience "weightlessness".

Clicker Question

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Astronauts aboard the International Space Station float around, experiencing weightlessness.

Why is this?

A) The force of gravity from the earth is zero on the Space Station
B) The force of gravity is much, much weaker on the Space Station
C) The Space Station has the "inertial dampers" turned on.
D) The Space Station is in circular orbit around the earth.
E) The Space Station generates an anti-gravity field.