September 27, 2010 Physics 121 Prof. E. F. Redish

- **Theme Music: Gravity**
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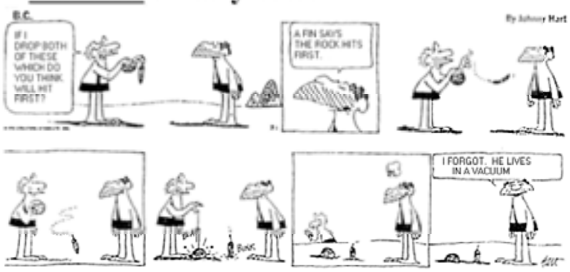
- **Cartoon: Johnny Hart**



Outline

- Quiz 3 on acceleration
- Recap of Newton's Laws
- Gravity

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Footholds 2.0
Revised summary of Newton's Laws

- Newton 0:
  - Objects only feel pForces when something touches them. An object responds to the pForces it feels when it feels them.
- Newton 1:
  - An object that feels a net pForce of 0 keeps moving with the same velocity (which may = 0).
- Newton 2:
  - An object that is acted upon by other objects changes its velocity according to the rule $\vec{a} = \vec{F}^{net}/m$
- Newton 3:
  - When two objects interact the pForces they exert on each other are equal and opposite. $\vec{F}_{A\to B} = -\vec{F}_{B\to A}$

"Net pForce" = vector sum of all the pForces acting on the object.

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Force-labeling convention

- According to our foothold idea, forces are what objects do to each other when they touch.
- If a force is a
  - normal force we label it as N
  - tension force we label it as T
  - friction force we label it as f
- We put subscripts on each force telling *who* is acting on *whom.*

$$\vec{F}_{(\text{object causing force})\rightarrow(\text{object feeling force})}$$

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Vertical motions

- If we no longer restrict our considerations to horizontal motions, we know objects can change their velocities when nothing is touching them.
- We have to either choose to reject our insights and laws developed from horizontal experiments or see if we can adapt them.

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Proposing Gravity

- Suppose we try to include vertical motions in our system by hypothesizing:
  - There is a non-touching force that acts on every object.
- Could some other object be causing it? What?
- What are its properties?
  - How does it depend on position? time?
  - How does it depend on the object?

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The Properties of Gravity

- How can we tell how the force of gravity depends on an object?
- Do you think the force of gravity is the same or different for different objects?
- Experiment: See how it behaves when gravity is the <u>only</u> force acting on it. We expect it to speed up (accelerate). How does that acceleration depend on the object?

$$\vec{a} = \frac{\vec{W}}{m}$$

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The Gravitational Field Strength

- We find that, <u>when we can ignore the effects of other objects (the air)</u>, that all objects accelerate the same in free fall (only *W* acting).

$$\vec{a} = \frac{\vec{W}}{m} = \vec{g}$$

- Experimentally, this is a constant independent of the object. Therefore: $\vec{W} = m\vec{g}$
- Define the constant g as the *gravitational field strength.* (Units of N/kg)

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Making sense

- Consider two experiences to see if we can make sense of this.
  - A. If I hold the light object and the heavy objects in my hands, which one is pulled more by gravity?
  - B. If I kick a soccer ball and a cannon ball with the same kick, which one will speed away faster?

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Foothold Ideas: Gravity

- Every object (near the surface of the earth) feels a downward pull proportional to its mass:

$$\vec{W}_{E\rightarrow m} = m\vec{g}$$

where $\vec{g}$ is referred to as *the gravitational field.*

- This is a pForce even though nothing touching the object is responsible for it.
- The gravitational field has the same magnitude for all objects irrespective of their motion and at all points.
- The gravitational field always points down.
- It is measured to be $g \approx 9.8$ N/kg

What object causes W?

Why N/kg instead of m/s^2?

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Newton's Laws: 3.0

*A **pForce** is what two objects do to each other when they touch that can change each others' velocities. Measured by the stretch of a spring.*

- Newton 0:
  - Objects only feel pForces when something touches them plus the effect of gravity (which does not require touching). An object responds to the forces it feels when it feels them.
- Newton 1:
  - An object that feels a net pForce of 0 keeps moving with the same velocity (which may = 0).
- Newton 2:
  - An object that is acted upon by other objects changes its velocity according to the rule $\vec{a} = \vec{F}^{net} / m$
- Newton 3:
  - When two objects interact the pForces they exert on each other are equal and opposite. $\vec{F}_{A\rightarrow B} = -\vec{F}_{B\rightarrow A}$

Response to Gravity: Free Fall

- After an object has been released,
  - if it is dense enough so the forces from the air can be ignored
  - if nothing else is touching it

  the only force acting on it is gravity.

$$\vec{a} = \vec{F}^{net} / m = \vec{W}_{E\rightarrow m} / m = m\vec{g} / m = \vec{g}$$

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Is it really true that air is what makes a difference for light objects?

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Calculating the motion of a body in free fall

- Free-fall doesn't just mean "falling". It means "there are no other pForces that have to be considered other than gravity."
- Consider up and down motion only.

$$a = \frac{F^{net}}{m} = \frac{W_{E\to m}}{m} = \frac{mg}{m} = g$$

$$\langle a \rangle = g = \frac{\Delta v}{\Delta t} \qquad \langle v \rangle = \frac{\Delta y}{\Delta t}$$

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Example

- Suppose I throw the ball upward and it leaves my hand with a velocity v_0. How far up does it go and how long does it go upward?

$$g = \frac{\Delta v}{\Delta t} \qquad \langle v \rangle = \frac{\Delta y}{\Delta t}$$

$$v_i = v_0 \qquad y_i = 0 \qquad t_i = 0$$

$$v_f = 0 \qquad y_f = h \qquad t_f = T$$

$$g = \frac{v_f - v_i}{t_f - t_i} \qquad \langle v \rangle = \frac{y_f - y_i}{t_f - t_i}$$

$$g = \frac{v_0}{T} \qquad \langle v \rangle = \frac{h}{T}$$

$$\langle v \rangle = \frac{v_i + v_f}{2} = \frac{v_0}{2}$$

$$T = \frac{v_0}{g} \qquad \frac{v_0}{2} = \frac{h}{T}$$

$$h = \tfrac{1}{2} v_0 T = \frac{v_0^2}{2g} = \tfrac{1}{2} g T^2$$

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