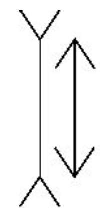
- **Theme Music:** Duke Ellington
  Take the A Train
- **Cartoon:** Lynn Johnson
  For Better or for Worse

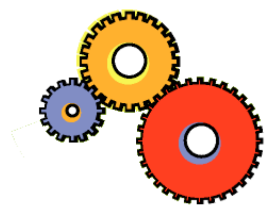
Knowledge Games

- Shopping for ideas
- Choosing foothold ideas
- Reconciling intuition
- Multiple representations






- Elaboration / Implication
- Seeking consistency
- Sense making



Estimation: Some numbers I will expect you to know

- Numbers
  - number of UG students at UMd ~ 25,000 2.5×10^4
  - number of people in MD ~ 4-5 million 4.5×10^6
  - number of people in USA ~ 300 million 3.0×10^8
  - number of people in world ~ 6 billion 6.5×10^9
- Distances
  - distance across DC ~10 miles
  - distance across USA ~3000 miles
  - distance around the world ~24,000 miles
  - radius of the earth $= 2/\pi \times 10^7$ m

Causes of Motion: Newton's Laws

- **N0**: Objects only respond to forces on themselves, at the time those forces are exerted.
- **N1**: Objects change their velocity (perhaps = 0) only if they are acted on by unbalanced forces.
- **N2**: Each object responds to the forces it feels by changing its velocity according to

$$\vec{a} = \vec{F}^{net} / m$$

- **N3**: When two objects touch, they exert equal and opposite forces on each other.

$$\vec{F}_{A \to B} = -\vec{F}_{B \to A}$$

Kinds of forces

- There are 2 classes of forces
  - Touching
    - Normal — N (perpendicular to surface and pressing in)
    - Tension — T (pulling out of the surface)
    - Friction — f (parallel to surface — opposing sliding)
  - Non-touching
    - Gravity — W
    - Electric — F^{elec}
    - Magnetic — F^{mag}

Properties of Forces

- *Normal* — adjust to oppose compression (like a spring)
- *Tension* — t. force vs. t. scalar, analysis of the chain

$$T = k\,\Delta l$$

- *Friction* — opposes sliding of surfaces over one another

$$f_{A\to B} \le f_{A\to B}^{\max} = \mu_{AB}^{static} N_{A\to B} \quad \text{not sliding}$$

$$f_{A\to B} = \mu_{AB}^{kinetic} N_{A\to B} \quad \text{sliding}$$

$$\mu_{AB}^{kinetic} \le \mu_{AB}^{static}$$

- Gravity — towards the center of the earth, proportional to mass

$$\vec{W} = -\frac{GmM}{R^2}\hat{R} \approx m\vec{g}$$

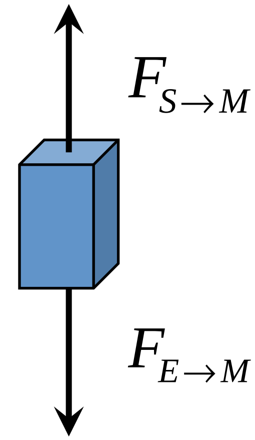
Math

- Dimensional analysis
- Shifting functions
- Properties of trig functions, large angles
- Functions of two variables
- Small angle approximation

Foothold ideas: Mass on a spring

- There is an equilibrium (balance) point where the mass can stay without moving.
- Whichever way the mass moves, the force is in the direction of pushing it back to its equilibrium position.
- When it gets back to its equilibrium, it's still moving so it overshoots.

Summary with Equations: Mass on a spring



$$a = \frac{1}{m} F^{net} \qquad F^{net} = -kx$$

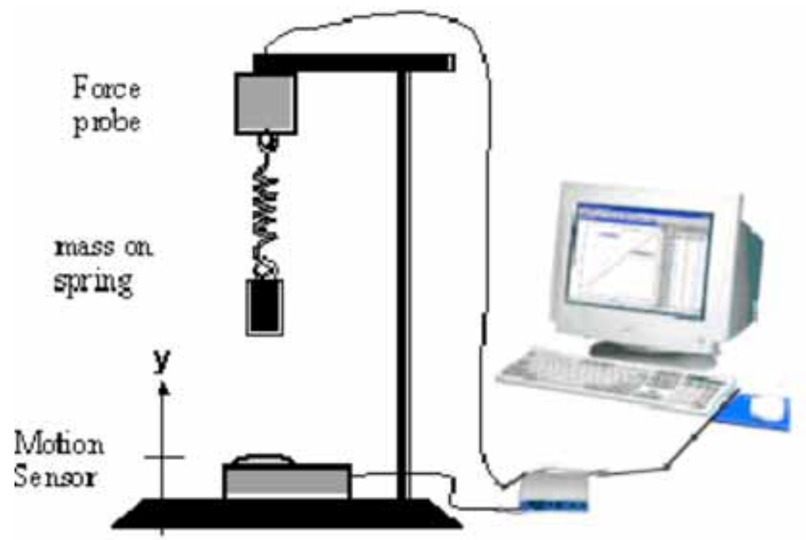
Measured from where?

$$a = -\omega_0^2 x \qquad \omega_0^2 = \frac{k}{m}$$

$$x(t) = A\cos(\omega_0 t - \phi)$$

$$\omega_0 = \frac{2\pi}{T}$$

Interpret!



Foothold Ideas: Energy and Work

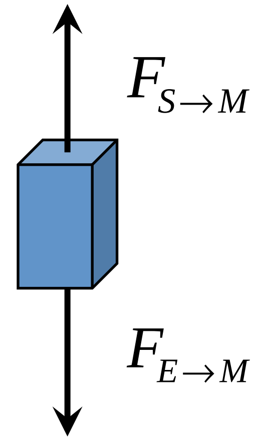
- We can rewrite N2 to focus on the part of the forces that change the object's speed.
- Define Kinetic Energy and Work

$$KE = \tfrac{1}{2} m v^2 \qquad \text{Work} = \vec{F}^{net} \cdot \Delta\vec{r}$$

- Rewrite N2 by taking the dot product with the displacement (to select part of force acting along the motion)

$$\Delta\left(\tfrac{1}{2} m v^2\right) = \vec{F}^{net} \cdot \Delta\vec{r}$$

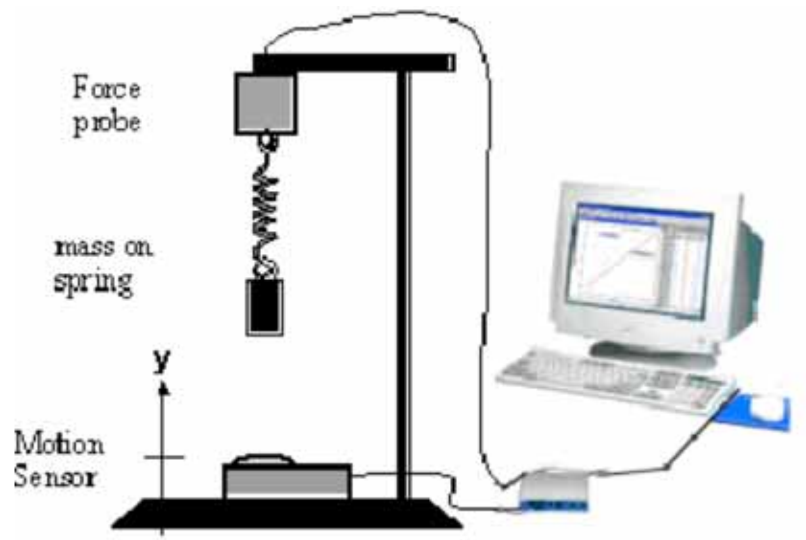
Summary with Equations: Mass on a spring (Energy)



Measured from where?

$$E = \tfrac{1}{2}mv^2 + mgh + \tfrac{1}{2}k(\Delta l)^2$$

$$E_i = E_f$$

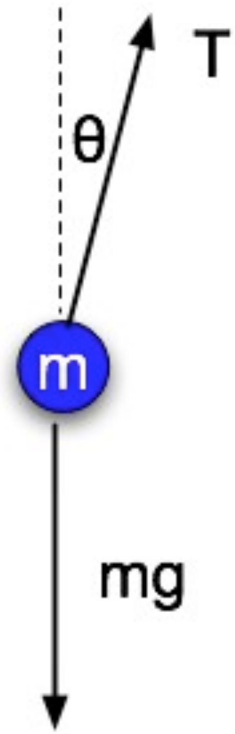


The pendulum equations

$$\vec{a} = \frac{1}{m}\vec{F}^{net} = \frac{1}{m}\left(\vec{T} + m\vec{g}\right)$$

$$F_x^{net} = T\sin\theta$$

$$F_y^{net} = T\cos\theta - mg$$



Very little up and down motion.

Mostly left and right.

$$a_x = -\frac{1}{m}T\sin\theta = -\frac{T}{m}\frac{x}{L}$$

$$a_y \approx 0 = \frac{1}{m}\left(T\cos\theta - mg\right)$$

$$\Longrightarrow$$

$$T \approx mg$$

$$a_x = -\frac{g}{L}x$$

Pendulum motion

$$a_x = -\frac{g}{L}x \quad \Longrightarrow \quad a_x = -\omega_0^2 x, \qquad \omega_0^2 = \frac{g}{L}$$

Same as mass on a spring!
Just with a different ω_0.

What's the period?
Why doesn't it depend on m?
What does the energy look like in this case?

Foothold principles: Mechanical waves

- *Key concept*: We have to distinguish the motion of the bits of matter and the motion of the pattern.
- *Pattern speed*: a disturbance moves into a medium with a speed that depends on the properties of the medium (but not on the shape of the disturbance)
- *Matter speed*: the speed of the bits of matter depend on both the size and shape of the pulse and on the pattern speed.

$$v_0 = \sqrt{\frac{TL}{M}} = \sqrt{\frac{T}{\mu}}$$

- *Superposition*: when one or more disturbances overlap, the result is that each point displaces by the sum of the displacements it would have from the individual pulses. (signs matter)
- *Mechanism*: the pulse propagates by each bit of string pulling on the next.

Sinusoidal waves

- Suppose we make a continuous wiggle. When we start our clock (t = 0) we might have created shape something like

$$y = A\sin kx$$

- At later times this would look like

$$y = A\sin k(x - v_0 t)$$

Rewrite this as: $\longrightarrow$ $y = A\sin(kx - kv_0 t) = A\sin(kx - \omega t)$

$$\omega = kv_0$$

Interpretation

$$y = A\sin(kx - \omega t) \qquad \omega \equiv kv_0$$

Fixed time: Wave goes a full cycle when

$$kx : 0 \rightarrow 2\pi$$

$$x : 0 \rightarrow \frac{2\pi}{k} \equiv \lambda$$ (wavelength)

Fixed position: Wave goes a full cycle when

$$\omega t : 0 \rightarrow 2\pi$$

$$t : 0 \rightarrow \frac{2\pi}{\omega} \equiv T$$ (period)

Find the dog

$\omega = kv_0$?

Interpret

$$\omega = 2\pi f = \frac{2\pi}{T} \qquad k = \frac{2\pi}{\lambda}$$

$$\omega = kv_0 \quad \Rightarrow \quad 2\pi f = \frac{2\pi}{\lambda} v_0 \quad \text{or}$$

$f\lambda = v_0$ (famous wave formula)

Interpret

$$\frac{1}{T}\lambda = v_0 \quad \Rightarrow \quad \lambda = v_0 T$$

Foothold Ideas
Light: The Physics

- Certain objects (the sun, bulbs,…) give off light.
- In empty space light travels in straight lines.
- Each point on an object scatters light, spraying it off in all directions.
- A polished surface reflects rays back again according to the rule: *The angle of incidence equals the angle of reflection*.
- When a ray of light enters a transparent medium at an angle it bends by the rule

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Foothold Ideas
Light: The Psycho-physiology

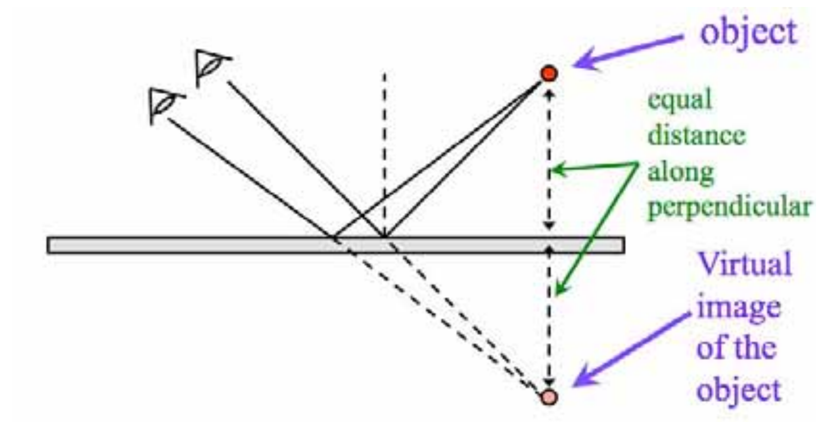
- We only see something when light coming from it enters our eyes.
- Our eyes identify a point as being on an object when rays traced back converge at that point.

Kinds of Images

- Real
  - When the rays seen by the eye do converge at a point, the image is called *real*.
  - If a screen is put at the real image, the rays will scatter in all directions and an image can be seen on the screen, just as if it were an object.
- Virtual
  - When the rays seen by the eye extrapolate to a point but don't meet, the image is called *virtual*.
  - If a screen is put at the virtual image we see nothing on it since no rays are actually there.

Mirrors and Ray Tracing

- Flat mirrors
  - The image is virtual, behind the mirror the same distance the object is in front of the mirror.



- Curved mirrors
  - Focal point $f = R/2$
  - Three easy-to-figure rays
  - Real and virtual images