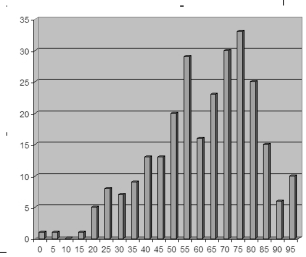
Physics 207, Lecture 10, Oct. 9

- MidTerm I
- Exams will be returned in your next discussion section
- Regrades: Write down, on a separate sheet, what you want regraded and why.

Mean: 64.6
Median: 67
Std. Dev.: 19.0
Range: High 100 Low 5
Solution posted on
http://my.wisc.edu
Nominal curve (conservative):

86-100 A
70-85 B or A/B
40-69 C or B/C
35-40 marginal
25-35 D
Below 25 F



Physics 207, Lecture 10, Oct. 9

Agenda: Chapter 7, Work and Energy Transfer

- Definition of Work (a scalar quantity)
- Variable force devices (e.g., Hooke's Law spring)
- Work/Energy Theorem
  - ❖ $W = \Delta K$
- Kinetic Energy
  - ❖ $K = 1/2\ mv^2$
- Power (on Wednesday)
  - ❖ $P = dW / dt = \mathbf{F} \cdot \mathbf{v}$

Assignment: For Wednesday read Chapter 8

- WebAssign Problem Set 4 due Tuesday next week (start now)

Work & Energy

- One of the most important concepts in physics.
  - ❖ Alternative approach to mechanics.
- Many applications beyond mechanics.
  - ❖ Thermodynamics (movement of heat or particles).
  - ❖ Quantum mechanics...
- Very useful tools.
  - ❖ You will learn a complementary approach (often much easier) way to solve problems. But there is no free lunch….easier but there are fewer details that are explicitly known.

See text: 7-1

Energy Conservation

- Energy cannot be destroyed or created.
  - ❖Just changed from one form to another.
- We say ***energy is conserved*** !
  - ❖True for any *isolated* system.
- Doing "**work**" on an otherwise isolated system will change it's "**energy**"...

See text: 7-1

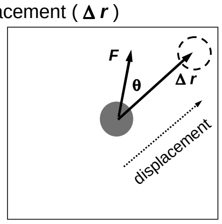
Definition of Work, The basics

Ingredients: Force ($\mathbf{F}$), displacement ($\Delta \mathbf{r}$)

Work, W, of a constant force $\mathbf{F}$ acting through a displacement $\Delta \mathbf{r}$ is:

$W = \mathbf{F} \cdot \Delta \mathbf{r}$ (Work is a scalar)

"Scalar or Dot Product"

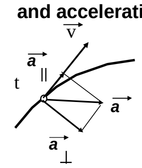


Work tells you something about <u>what happened on the path</u>!

Did something do work on you? Did you do work on something?

Simplest case (**no** frictional forces and **no** non-contact forces)
Did your **speed** change? (what happened to | **v** | !!!)

Remember that a path evolves with time and acceleration implies a force acting on an object



$\vec{a} = \vec{a}_{\parallel} + \vec{a}_{\perp}$

$\vec{a} = \vec{a}_{tang} + \vec{a}_{radial}$

$\vec{F} = \vec{F}_{tang} + \vec{F}_{radial}$

$\vec{a} \neq 0$

Two possible options:

Change in the magnitude of $\vec{v}$ $\quad \vec{a}_{\parallel} \neq 0$

Change in the direction of $\vec{v}$ $\quad \vec{a}_{\perp} \neq 0$

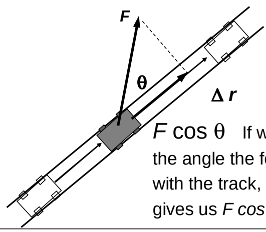
- A tangetial force is the important one for work!
  - ❖ How long (time dependence) gives the kinematics
  - ❖ The distance over which this force$_{Tang}$ is applied: Work

Definition of Work...

- Only the component of ***F*** along the path (i.e. "displacement") does work.

<u>The vector dot product does that automatically.</u>

- ❖ Example: Train on a track.



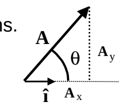
$F \cos\theta$ If we know the angle the force makes with the track, the dot product gives us $F \cos\theta$ and Δr

Physics 207: Lecture 10, Pg 7

Review: Scalar Product (or Dot Product) 7.3

- Useful for performing projections.

$\mathbf{A} \bullet \hat{\mathbf{i}} = A_x$



- Calculation is simple in terms of components.

$\mathbf{A} \bullet \mathbf{B} = (A_x)(B_x) + (A_y)(B_y) + (A_z)(B_z)$

Calculation also in terms of magnitudes and relative angles.

$\mathbf{A} \bullet \mathbf{B} \equiv |A||B| \cos\theta$

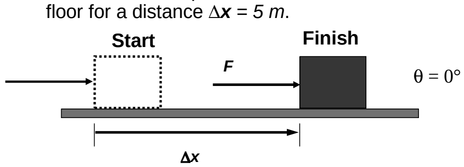
You choose the way that works best for you!

Physics 207: Lecture 10, Pg 8

See text: 7-1

Work: 1-D Example (constant force)

- A force ***F*** = *10 N* pushes a box across a **frictionless** floor for a distance Δ***x*** = *5 m*.



- Work is $\mathbf{A} \bullet \mathbf{B} \equiv |A||B| \cos\theta = F\,\Delta x = 10 \times 5$ N m = 50 J
- 1 Nm is defined to be 1 Joule and this is a unit of energy
- Work reflects energy transfer

See example 7-1: Pushing a trunk. Physics 207: Lecture 10, Pg 9

See text: 7-1

Units:

Force x Distance = Work

Newton x Meter = Joule

$[M][L] / [T]^2$ [L] $[M][L]^2 / [T]^2$

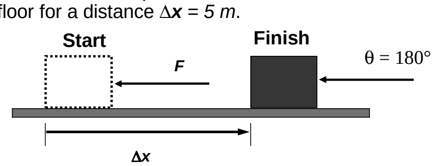
mks	cgs	Other
N-m (Joule)	Dyne-cm (erg) = 10^{-7} J	BTU = 1054 J calorie = 4.184 J foot-lb = 1.356 J eV = 1.6×10^{-19} J

Physics 207: Lecture 10, Pg 10

See text: 7-1

Work: 1-D 2nd Example (constant force)

- A force ***F*** = *10 N* pushes a box across a **frictionless** floor for a distance Δ***x*** = *5 m*.



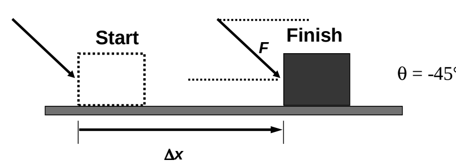
- Work is $\mathbf{A} \bullet \mathbf{B} \equiv |A||B| \cos\theta = F\,\Delta x\,(-1) = -10 \times 5$ N m = -50 J
- **Work reflects energy transfer**

See example 7-1: Pushing a trunk. Physics 207: Lecture 10, Pg 11

See text: 7-1

Work: 1-D 3rd Example (constant force)

- A force ***F*** = *10 N* pushes a box across a **frictionless** floor for a distance Δ***x*** = *5 m*.



- Work is $\mathbf{A} \bullet \mathbf{B} \equiv |A||B| \cos\theta = F\,\Delta x\; 0.71 = 50 \times 0.71$ Nm = 35 J
- Work reflects energy transfer

See example 7-1: Pushing a trunk. Physics 207: Lecture 10, Pg 12

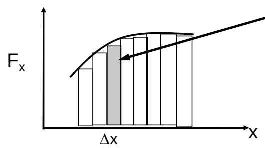
Text : 7.3

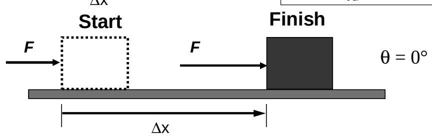
Work and Varying Forces

- Consider a varying force F(x)

Area = $F_x \Delta x$
F is **increasing**
Here $W = \mathbf{F} \cdot \Delta \mathbf{r}$
becomes $dW = F\,dx$

$$W = \int_{x_i}^{x_f} F(x)\,dx$$



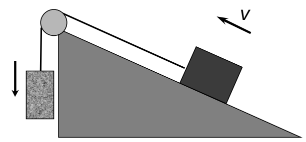


Work is a scalar, the catch is that there is no time/position info on hand

Lecture 10, *Exercise 1*
Work in the presence of friction and non-contact forces

- A box is pulled up a rough (μ > 0) incline by a rope-pulley-weight arrangement as shown below.
  - ❖ How many forces are doing work on the box ?
  - ❖ Of these which are positive and which are negative?
  - ❖ Use a Force Body Diagram
  - ❖ Compare force and path

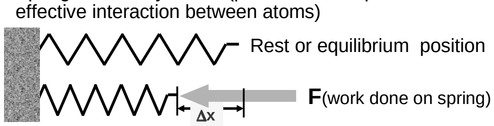
(A) *2*
(B) *3*
(C) *4*



Text : 7.3

A variable force device: A Hooke's Law Spring

- Springs are everywhere, (probe microscopes, DNA, an effective interaction between atoms)



- In this spring, the magnitude of the force increases as the spring is further compressed (a displacement).
- Hooke's Law,

$F_S = -k\,\Delta x$

Active Figure

Δx is the amount the spring is stretched or compressed from it resting position.

Lecture 10, *Exercise 2*
Hooke's Law

- Remember Hooke's Law,

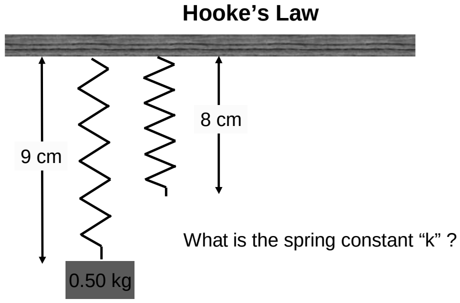
$F_x = -k\,\Delta x$

What are the units for the constant *k* ?

(A) $\frac{\text{kg m}^2}{\text{s}^2}$ (B) $\frac{\text{kg m}}{\text{s}^2}$ (C) $\frac{\text{kg}}{\text{s}^2}$ (D) $\frac{\text{kg}^2\ \text{m}}{\text{s}^2}$

F is in kg m/s^2 and dividing by m gives kg/s^2 or N/m

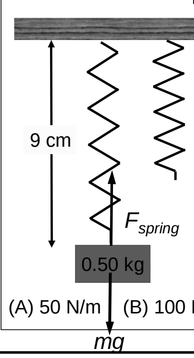
Lecture 10, *Exercise 3*
Hooke's Law



What is the spring constant "k" ?

(A) 50 N/m (B) 100 N/m (C) 400 N/m (D) 500 N/m

Lecture 10, *Exercise 3*
Hooke's Law



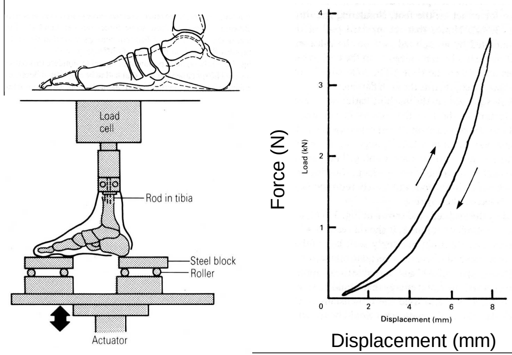
What is the spring constant "k" ?

$\Sigma F = 0 = F_s - mg = k\,\Delta x - mg$

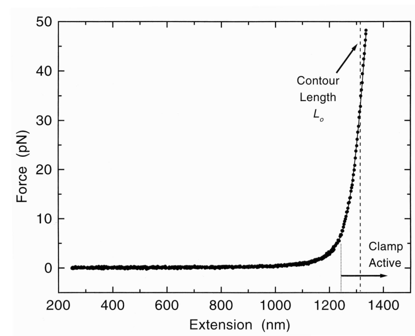
Use $k = mg/\Delta x$ = 5 N / 0.01 m

(A) 50 N/m (B) 100 N/m (C) 400 N/m **(D) 500 N/m**

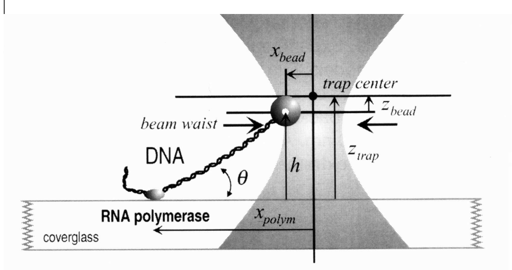
F-x relation for a foot arch:



F-x relation for a single DNA molecule

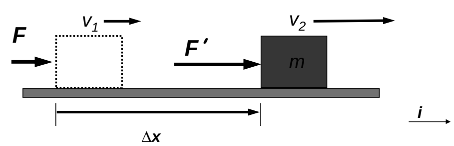


Measurement technique: optical tweezers



Work & Kinetic Energy:
Energy transfer involving changes in speed

- A force, $F = 10\ N$, pushes a box across a frictionless floor for a distance $\Delta \mathbf{x} = 5m$.
- The speed of the box is v_1 before the push, and v_2 after the push.
- Consider only this force and the box
- Relate the work to the kinetic energy of the box



See text: 7-4

Work Kinetic-Energy Theorem:

{***Net Work*** done on object}
=
{***change*** in ***kinetic energy*** of object}

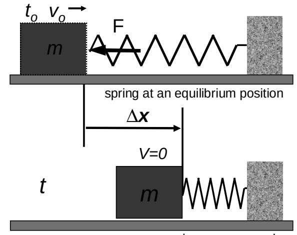
$$W_{net} = \Delta K$$

$$= K_2 - K_1 \qquad \text{(final – initial)}$$

$$= \frac{1}{2} m v_2^{\,2} - \frac{1}{2} m v_1^{\,2}$$

Example: Work Kinetic-Energy Theorem

- How much will the spring compress (i.e. $\Delta \mathbf{x}$) to bring the object to a stop (i.e., $v = 0$) if the object is moving initially at a constant velocity (v_o) on frictionless surface as shown below ?



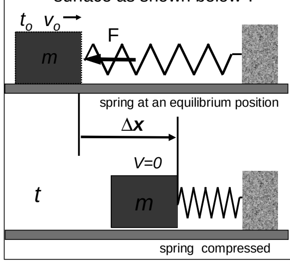
Notice that the spring force is opposite to the displacemant.

For the mass m, work is negative

For the spring, *work is positive*

Example: Work Kinetic-Energy Theorem

- How much will the spring compress (i.e. $\Delta \mathbf{x} = x_f - x_i$) to bring the object to a stop (i.e., $v = 0$) if the object is moving initially at a constant velocity (v_o) on frictionless surface as shown below ?



$$W_{\text{box}} = \int_{x_i}^{x_f} F(x)\, dx$$

$$W_{\text{box}} = \int_{x_i}^{x_f} -kx\, dx$$

$$W_{\text{box}} = -\tfrac{1}{2} kx^2 \Big|_{x_i}^{x_f}$$

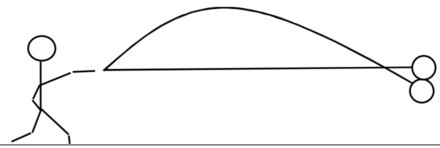
$$W_{\text{box}} = -\tfrac{1}{2} k\, \Delta x^2 = \Delta K$$

$$-\tfrac{1}{2} k\, \Delta x^2 = \tfrac{1}{2} m 0^2 - \tfrac{1}{2} m v_0^2$$

Lecture 10, *Exercise 4*
Kinetic Energy

- To practice your pitching you use two baseballs. The first time you throw a slow curve and clock the speed at 50 mph (~25 m/s). The second time you go with high heat and the radar gun clocks the pitch at 100 mph. What is the ratio of the kinetic energy of the fast ball versus the curve ball ?

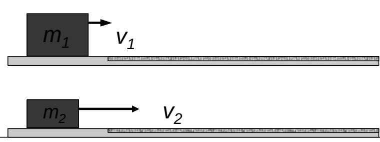
(A) 1/4 (B) 1/2 (C) 1 (D) 2 (E) 4



Lecture 10, *Exercise 5*
Work & Friction

- Two blocks having mass m_1 and m_2 where $\mathbf{m_1 > m_2}$. They are sliding on a frictionless floor and have the same kinetic energy when they encounter a long rough stretch (i.e. $\mu > 0$) which slows them down to a stop.
- Which one will go farther before stopping?
- **Hint:** How much work does friction do on each block ?

(A) m_1 (B) m_2 (C) They will go the same distance



Physics 207, Lecture 10, Recap

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