

- **Theme Music: Duke Ellington**

Take the A Train

- **Cartoon: Lynn Johnston**

For Better or for Worse



Note:

- These Foothold slides cover the last third of the class. Since the final exam is cumulative, you should also look at the summary slides on
 - 10/7 (click on “Midterm 1” on the Schedule Page)
 - 11/11 (click on “Midterm 2” on the Schedule Page)
- Other resources include
 - clicker questions from each class (Schedule Page)
 - Midsemester exams and makeup exams (on Canvas under “Files”)

Results from all Exams

Acceleration graphs

Scaling and counting

	#1	#2	#3	#4	#5
Exam 1	44%	71%	70%	68%	78%
Exam 1MU	53%	72%	35%	77%	64%
Exam 2	65%	50%	76%	76%	71%
Exam 2MU	85%	66%	32%	25%	51%

Buoyancy

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Physics 131

Foothold ideas: Incompressible Flow

- Flow = volume / sec
crossing an area.
- Flow in a pipe:
volume in = volume out
- Resistance to flow –
– Drag is proportional to v and L .

$$Q = Av$$

$$A_1 v_1 = A_2 v_2$$

$$\Delta P = ZQ$$

$$Z = 8\pi\mu \frac{L}{A^2}$$



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Foothold ideas: Kinetic Energy and Work



- Newton's laws tell us how velocity changes. The Work-Energy theorem tells us how speed (independent of direction) changes.
- Kinetic energy = $\frac{1}{2}mv^2$
- Work done by a force = $\vec{F} \cdot \Delta\vec{r}$ or $F_{\parallel}\Delta r$ (part of force \parallel to displacement)
- Work-energy theorem: $\Delta(\frac{1}{2}mv^2) = F_{\parallel}^{net} \Delta r$

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Foothold ideas: Potential Energy



- For some forces between objects (gravity, electricity, springs) the work only depends of the change in relative position of the objects. Such forces are called conservative.
- For these forces the work done by them can be written
$$\vec{F} \cdot \Delta\vec{r}_{rel} = -\Delta U$$
- U is called a *potential energy* and can be considered an energy of place belonging to the two objects that can be exchanged with KE.

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Physics 131

Foothold ideas: Potential Energy



- For some forces work only depends on the change in position. Then the work done can be written

$$\vec{F} \cdot \Delta\vec{r} = -\Delta U$$

U is called a *potential energy*.

- Gravity, $U_{gravity} = mgh$

Spring, $U_{spring} = \frac{1}{2} k(\Delta L)^2$

Electric Force, $U_{electric} = k_C Q_1 Q_2 / r_{12}$

Flat-earth gravity approximation

Hooke's law approximate model

Exact for point charges

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Physics 131

Dimensions and Units of Energy

- $[1/2 mv^2] = M \cdot (L/T)^2 = ML^2/T^2$
- $1 \text{ kg} \cdot \text{m}^2 / \text{s}^2 = 1 \text{ N} \cdot \text{m} = 1 \text{ Joule}$
- Other units of energy are common (and will be discussed later)
 - Calorie
 - eV (electron Volt)
 - erg (=1 g-cm²/s²)



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Power

- An interesting question about work and energy is the rate at which energy is changed or work is done. This is called *power*.

$$\text{Power} = \frac{\text{Energy change}}{\text{time to make the change}}$$

$$= \frac{\Delta W}{\Delta t} = \vec{F}^{net} \cdot \frac{\Delta \vec{r}}{\Delta t} = \vec{F}^{net} \cdot \vec{v} \quad (\text{for mechanical work})$$

- Unit of power
1 Joule/sec = 1 Watt

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Foothold ideas: Inter-atomic interactions

- The interaction between atoms arises from the combination of the electrical forces of its components (electrons and nuclei).
 - It can be quite complex and involve electron sharing and chemical bonds.
 - The complexity arises from the quantum character of electrons.
- Despite this complexity, a simple potential model summarizes many features of a two-atom interaction.



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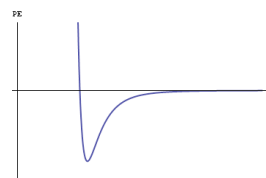
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Foothold ideas: Inter-atomic potentials



- The interaction between neutral atoms includes an attraction at long-range that arises from the fluctuating charge distribution in each atom; the PE behaves like $1/r^6$.
- When the atoms are pressed close, they repel each other strongly; both because the +nuclei repel and because of the Pauli principle (two electrons cannot be in the same state).
- Two commonly used models are:
 - The Lennard-Jones potential ($A/r^{12}-B/r^6$)
 - The Morse potential (exponentials)



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Foothold ideas: Conservation of Mechanical Energy



- Mechanical energy
 - The mechanical energy of a system of objects is conserved if resistive forces can be ignored.

$$\Delta(KE + PE) = 0$$

$$KE_{initial} + PE_{initial} = KE_{final} + PE_{final}$$

- Thermal energy
 - Resistive forces transform coherent energy of motion (energy associated with a net momentum) into *thermal energy* (energy associated with internal chaotic motions and no net momentum)

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Foothold ideas: Forces from PE



- For conservative forces, PE can be defined by

$$\vec{F} \cdot \Delta\vec{r} = -\Delta U$$

- If you know U , the force can be gotten from it via

$$F_{\parallel}^{type} = -\frac{\Delta U_{type}}{\Delta r} = -\frac{dU_{type}}{dr}$$

- In more than 1D need to use the *gradient*

$$\vec{F}^{type} = -\left(\frac{\partial U_{type}}{\partial x}\hat{i} + \frac{\partial U_{type}}{\partial y}\hat{j} + \frac{\partial U_{type}}{\partial z}\hat{k}\right) = -\vec{\nabla}U_{type}$$

- The force always points down the PE hill.

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Foothold ideas: Energies between charge clusters



- Atoms and molecules are made up of charges.
- The potential energy between two charges is

$$U_{12}^{elec} = \frac{k_C Q_1 Q_2}{r_{12}} \quad \text{No vectors!}$$

- The potential energy between many charges is

$$U_{12\dots N}^{elec} = \sum_{i<j=1}^N \frac{k_C Q_i Q_j}{r_{ij}} \quad \text{Just add up all pairs!}$$

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Foothold ideas: Bound states



- When two objects attract, they may form a *bound state* – that is, they may stick together.
- If you have to do positive work to pull them apart in order to get to a separated state with $KE = 0$, then the original state was in a state with negative energy.

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Foothold ideas: Non-conservative forces



- Work-energy theorem: $\Delta(\frac{1}{2}mv^2) = \vec{F}^{net} \cdot \Delta\vec{r}$
- For conservative forces (non-resistive), the work done by the force can be represented as a Potential Energy: $\vec{F} \cdot \Delta\vec{r} = -\Delta U$
- So when there are non-conservative forces, the work-energy theorem becomes:

$$\Delta(\frac{1}{2}mv^2 + U) = \vec{F}_{non-cons}^{net} \cdot \Delta\vec{r}$$

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Physics 131

Foothold ideas: Heat & Temperature 1



- Temperature is a measure of how hot or cold something is. (We have a natural physical sense of hot and cold.)
- When two objects are left in contact for long enough they come to the same temperature.
- When two objects of the same material but different temperatures are put together they reach an average, weighted by the fraction of the total mass.
- The mechanism responsible for the above rule is that the same thermal energy is transferred from one object to the other: Q proportional to $m\Delta T$.

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Foothold ideas: Heat & Temperature 2



- When two objects of different materials and different temperatures are put together they come to a common temperature, but it is not obtained by the simple rule.
- Each object translates thermal energy into temperature in its own way. This is specified by a density-like quantity, c , the specific heat.
- The heat capacity of an object is $C = mc$.
- When two objects of different material and different temperatures are put together they reach an average, weighted by the fraction of the total heat capacity.
- When heat is absorbed or emitted by an object $Q = \pm mc\Delta T$

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Foothold ideas: Heat flow



- Objects in contact at different temperatures will tend to exchange energies so that the hotter cools down, the cooler warms up, until they reach the same temperature. (0th Law)
- The rates at which thermal energy leaves or enters an object is a property of the material of which the object is made and its surface.
- When we touch an object, we measure the rate of flow of thermal energy – not temperature.

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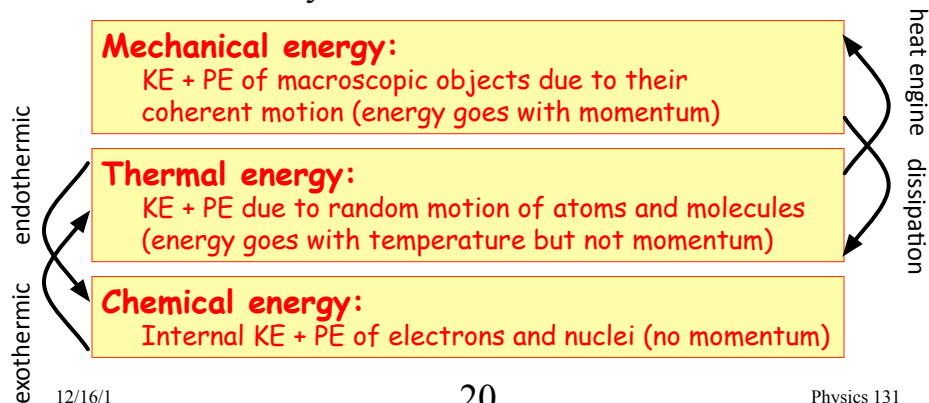
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Foothold ideas: Kinds of Energy



- All energy is kinetic + potential (or field energy). But depending what we choose to pay attention to, we may group them in different ways and treat them differently.



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Foothold ideas: Mechanical Energy & the 1st Law of Thermodynamics



Coherent energy
Kinetic and potential

Internal energy: random
motion of small stuff we
don't want to talk about

$$E = KE + PE + U_{\text{int}}$$

$$\Delta E = \Delta(KE) + \Delta(PE) + \Delta U_{\text{int}}$$

Energy of System
(not moving coherently)

Thermal energy
Entering system

Work done
on system

$$\Delta U_{\text{int}} = Q + W$$

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