PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 22000

General Physics

Lecture 10 – Work and Energy

Fall 2016 Semester

Prof. Matthew Jones

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First Midterm Exam

Tuesday, October 4th, 8:00-9:30 pm
Location: PHYS 112 and WTHR 200.

Covering material in chapters 1-6
(but probably not too much from chapter 6)

Multiple choice, probably about 25 questions, 15 will be conceptual, 10 will require simple computations.
A formula sheet will be provided.
You can bring one page of your own notes.

I put a couple exams from previous years on the web page.

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SUPPLEMENTAL INSTRUCTION

Free Study Sessions!

Rachel Hoagburg

Come to SI for more help in PHYS 220

Tuesday and Thursday	7:30-8:30PM Shreve C113

Office Hour
Tuesday 1:30-2:30 4th floor of Krach

For other SI-linked courses and schedules, visit purdue.edu/si or purdue.edu/boilerguide

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Last Lecture

- We learned that mass was a conserved quantity:

$$\begin{pmatrix} \textit{initial} \text{ mass of} \\ \text{system at earlier} \\ \text{clock reading} \end{pmatrix} + \begin{pmatrix} \textit{new} \text{ mass entering or} \\ \text{leaving system between} \\ \text{the two clock readings} \end{pmatrix} = \begin{pmatrix} \textit{final} \text{ mass of} \\ \text{system at later} \\ \text{clock reading} \end{pmatrix}$$

- We also learned that momentum was a conserved quantity:

$$p_f = p_i + J$$

$$\sum m_f v_f = \sum m_i v_i + \underbrace{\sum \bar{F} \Delta t}_{\text{Impulse}}$$

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The Importance of Conserved Quantities

- If we knew the forces at all times, and were willing to use calculus, we could calculate the motion of all objects.
- But, we can also ignore the details of the forces and rely on the fact that momentum is conserved:

$$m_1 \vec{v}_{1i} + m_2 \vec{v}_{2i} = m_1 \vec{v}_{1f} + m_2 \vec{v}_{2f}$$

- With no external impulses, the total momentum never changes, independent of how the objects interact with each other.

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Energy

- Another conserved quantity is energy.
- Unlike momentum, energy is a scalar quantity.
- You might already have an intuitive idea of what energy is, but in physics, we must define it precisely and use it consistently.

- So what exactly is energy?

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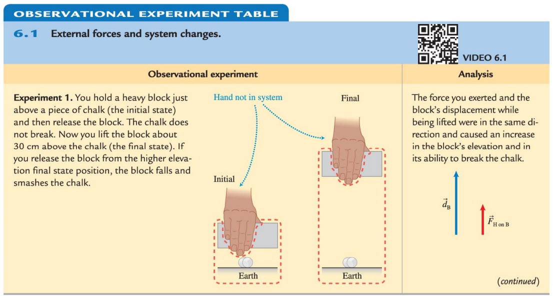
External Forces and System Changes



The block and the earth are parts of the system.

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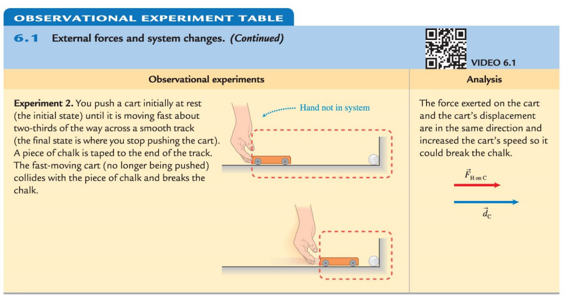
External Forces and System Changes



The cart and the wall are parts of the system.

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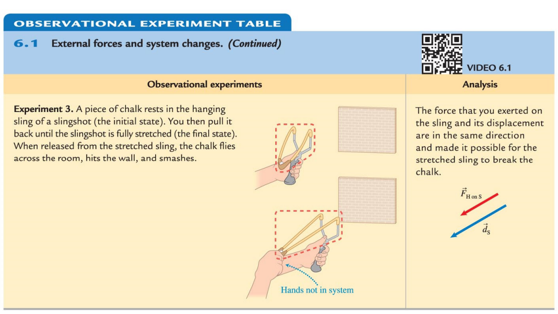
External Forces and System Changes



The slingshot and chalk are parts of the system.

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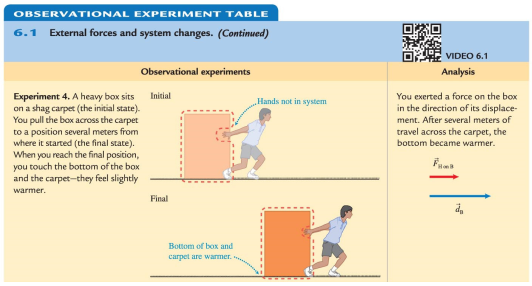
External Forces and System Changes



Observational experiments	Analysis
Experiment 4. A heavy box sits on a shag carpet (the initial state). You pull the box across the carpet to a position several meters from where it started (the final state). When you reach the final position, you touch the bottom of the box and the carpet—they feel slightly warmer.	You exerted a force on the box in the direction of its displacement. After several meters of travel across the carpet, the bottom became warmer.

The box and the floor are parts of the system.

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External Forces and System Changes

- The block with the higher elevation above the earth could break the chalk.
- The faster cart could break the chalk.
- The stretched slingshot could break the chalk.
- The box and the carpet it was pulled across became warmer, and through an unfortunate series of events, could break the chalk.

- “Energy” is kind of like the propensity for an object to break chalk:
  The more “energy” the system has, the easier it is to break the chalk.

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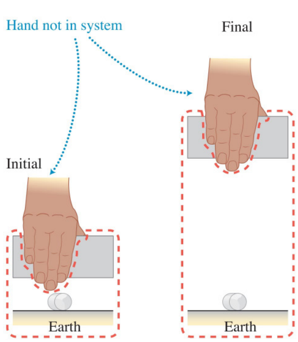
Gravitational Potential Energy

- The energy of an object-Earth system associated with the elevation of the object above Earth is called gravitational potential energy (symbol U_g).
- The higher above Earth the object is, the greater the gravitational potential energy.



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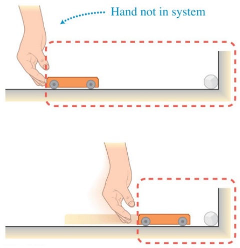
Kinetic Energy

- The energy due to an object's motion is called kinetic energy (symbol K).
- The faster the object is moving, the greater its kinetic energy.



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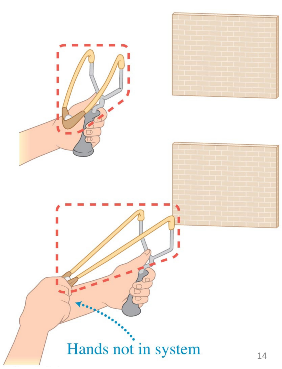
Elastic Potential Energy

- The energy associated with an elastic object's degree of stretch is called elastic potential energy (symbol U_s).
- The greater the stretch (or compression), the greater the object's elastic potential energy.



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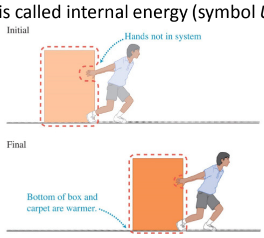
Internal Energy

- If a object slides on a surface, the surfaces in contact can become warmer.
- Structural changes in an object can occur when an external force is applied.
- The energy associated with both temperature and structure is called internal energy (symbol U_{int}).



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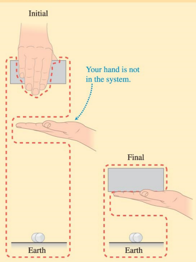
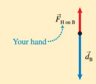
Negative Work

OBSERVATIONAL EXPERIMENT TABLE

6.2 Negative and zero work.

Observational experiment	Analysis
Experiment 1. A friend holds a block high above a piece of chalk (the initial state) and then releases it. Your hand catches and stops the block (the final state). The block's potential to break the chalk is greater in the initial state than in the final state.	The direction of the force exerted by your hand on the block is opposite the block's displacement and reduced the system's potential to break the chalk.





(continued)

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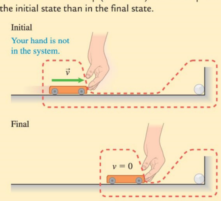
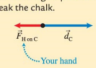
Negative Work

OBSERVATIONAL EXPERIMENT TABLE

6.2 Negative and zero work. *(Continued)*

Observational experiments	Analysis
Experiment 2. A cart is moving fast (the initial state) toward a piece of chalk taped on the wall. While it is moving, you push lightly on the moving cart opposite the direction of its motion, causing it to slow down and stop (final state). The cart's potential to break the chalk is greater in the initial state than in the final state.	The direction of the force exerted by your hand on the cart is opposite the cart's displacement and caused the moving cart to slow down and stop, thus reducing its potential to break the chalk.





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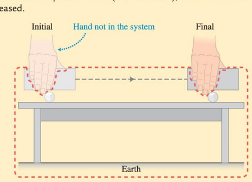
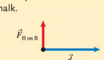
Zero Work

OBSERVATIONAL EXPERIMENT TABLE

6.2 Negative and zero work. *(Continued)*

Observational experiments	Analysis
Experiment 3. Your hand holds a block less than 1 cm above a piece of chalk (the initial state)—so close that the chalk would not break if the block is released. Your hand slowly moves the block to the right, keeping the block just above the tabletop until the block is less than 1 cm above a second piece of chalk (the final state), which also would not break if the block were released.	The direction of the force exerted by your hand on the block is perpendicular to the block's displacement and caused no change in the block's potential to break the chalk.





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Positive, Negative and Zero Work

- When the direction of the external force exerted on the system is in the ***same direction*** as the object's displacement, its ability to break chalk ***increases***.
- When the direction of the external force exerted on the system is ***opposite*** the object's displacement, its ability to break chalk ***decreases***.
- When the direction of an external force is ***perpendicular*** to an object's displacement, its ability to break chalk is ***unchanged***.

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Relating Work and Energy

- When the external force is in the direction of the object's displacement, it does positive work, causing the system to gain energy.
- If the external force points in the direction opposite to a system object's displacement, it does negative work, causing the energy of the system to decrease.
- If the external force points in a direction perpendicular to a system object's displacement, it does zero work on the system, causing no change to its energy.

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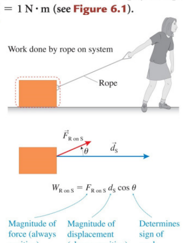
Defining work as a physical quantity

Work The work done by a constant external force $\vec{F}$ exerted on a system object while that system object undergoes a displacement $\vec{d}$ is

$$W = Fd\cos\theta. \quad (6.1)$$

where F is the magnitude of the force in newtons (always positive), d is the magnitude of the displacement in meters (always positive), and θ is the angle between the direction of $\vec{F}$ and the direction of $\vec{d}$. The sign of $\cos\theta$ determines the sign of the work. Work is a scalar physical quantity. The unit of work is the joule (J); 1 J = 1 N · m (see **Figure 6.1**).



$$W = Fd\cos\theta$$

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Positive, Negative and Zero Work

- In some experiments, force and displacement were in the same direction: θ = 0° and cos 0° = +1.0. Positive work was done.
- In other experiments, force and displacement were in opposite directions: θ = 180° and cos 180° = –1.0. Negative work was done.
- In one experiment, force and displacement were perpendicular to each other: θ = 90° and cos 90° = 0. Zero work was done.

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Important Tip

- It is tempting to equate the work done on a system with the force that is exerted on it.
- In physics, there must be a displacement of a system object for an external force to do work.
- **Force and work are not the same thing.**

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Example: Pushing a Bicycle

- Two friends are cycling up a hill inclined at 8°—steep for bicycle riding. The stronger cyclist helps his friend up the hill by exerting a 50-N pushing force on his friend's bicycle and parallel to the hill, while the friend moves a distance of 100 m up the hill. The force exerted on the weaker cyclist and the displacement are in the same direction.
- Determine the work done by the stronger cyclist on the weaker cyclist.

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Tip for Calculating Work

- The angle that appears in the definition of work is the angle between the external force and the displacement of the system object.
- When calculating work, it is useful to draw tail-to-tail arrows representing the external force doing the work and the system object displacement. Then note the angle between the arrows.

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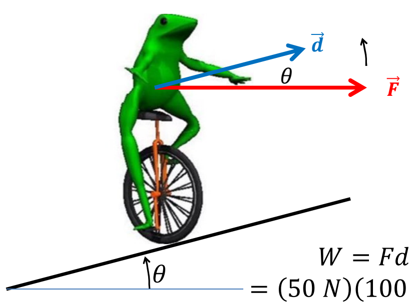
Example: Pushing a Bicycle (or Unicycle)



$$W = Fd\cos\theta$$
$$= (50\ N)(100\ m)\cos(8°)$$
$$= 4950\ N \cdot m$$

Energy is a Conserved Quantity

- Work done on a system object by an external force results in a change of one or more types of energy in the system: kinetic energy, gravitational potential energy, elastic potential energy, or internal energy.
- The energy of a system can also be converted from one form to another.
  - **Can this happen when the work done is zero?**

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Total Energy

- The total energy *U* of a system is the sum of all these energies in the system:

$$\text{Total Energy} = U = K + U_g + U_s + U_{int}$$

- Hypothesis: if no work is done on the system, the energy of the system should not change; it should be constant.

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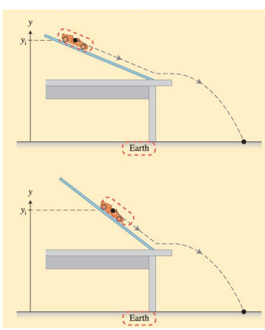
Is the Energy of an Isolated System Constant?



When released from the same vertical height with respect to the table, the car lands the same distance from the table.

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Conservation of Energy

- We have support for a hypothesis that the energy of an isolated system is constant and the different processes inside the system convert energy from one form to another.
- We reason that work is a mechanism through which the energy of a nonisolated system changes.
  - Based on this reasoning, we can hypothesize that energy is a conserved quantity—that it is constant in an isolated system and changes as a result of work done on a nonisolated system.

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Work-Energy Bar Charts

- A work-energy bar chart indicates the relative amounts of a system's different types of energy in the initial state of a process, the work done on the system by external forces during the process, and the relative amounts of different types of energy in the system at the end of the process.
- The work bar is shaded to emphasize that work does not reside in the system.

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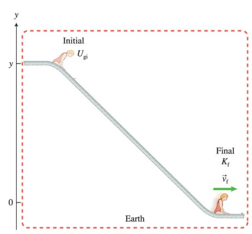
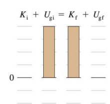
Example: Work-Energy Bar Chart

Table 6.4 Three examples of system energy conversions.

Description of process	Sketch of the system and initial-final state	Bar chart for the process
(1) A girl starts at rest at the top of a smooth water slide and is moving fast at the bottom. $U_g \rightarrow K$ The system's gravitational potential energy is converted to the girl's kinetic energy as she moves down the slide.		

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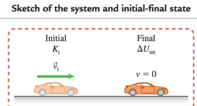
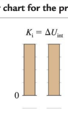
Example: Work Energy Bar Chart

Table 6.4 Three examples of system energy conversions. *(Continued)*

Description of process	Sketch of the system and initial-final state	Bar chart for the process
(2) A fast-moving car skids to a stop on a level road. $K \rightarrow U_{int}$ The system's kinetic energy is converted to internal thermal energy due to friction.		

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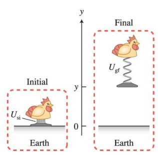
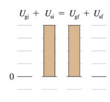
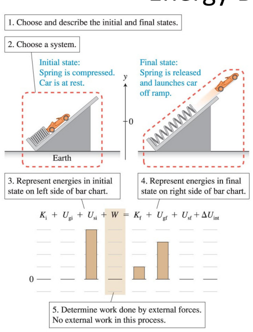
Example: Work-Energy Bar Chart

Table 6.4 Three examples of system energy conversions. *(Continued)*

Description of process	Sketch of the system and initial-final state	Bar chart for the process
(3) A pop-up toy is compressed and when released pops up to a maximum height of 0.50 m. $U_s \rightarrow U_g$ The system's elastic potential energy is converted to gravitational potential energy.		

Example: Constructing a Qualitative Work-Energy Bar Chart



- The system is isolated:
  - no work is done on it.
- If the earth was not included in the system, then the earth would do negative work on the car.
  - In such a system, there would be *no gravitational potential energy*.

Generalized Work-Energy Principle

Generalized work-energy principle The sum of the initial energies of a system plus the work done on the system by external forces equals the sum of the final energies of the system:

$$U_i + W = U_f \qquad (6.3)$$

or

$$(K_i + U_{gi} + U_{si}) + W = (K_f + U_{gf} + U_{sf} + \Delta U_{int}) \qquad (6.3)$$

Note that we have moved $U_{int\,i}$ to the right hand side ($\Delta U_{int} = U_{int\,f} - U_{int\,i}$) since values of internal energy are rarely known, while internal energy changes are.