

Physics 121.
Lecture 11.



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Physics 121.
Tuesday, February 26, 2008.

- Course Information
- Topics to be discussed today:
 - Review of Conservation Laws (kinetic energy, potential energy, conservative and non-conservative forces).
 - Dissipative forces.
 - Gravitational potential energy.

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Conservation of energy.
A review.

- The mechanical energy of a system is defined as the sum of the kinetic energy K and the potential energy U :

$$E = K + U$$

- If the total mechanical energy is constant, we must require that $\Delta E = 0$, or

$$\Delta K + \Delta U = 0$$

- We conclude that any change in the kinetic energy ΔK must be accompanied by an equal but opposite change in the potential energy ΔU .

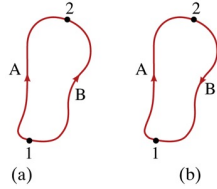
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Conservation of energy. A review.

- Per definition, the change in potential energy is related to the work done by the force.
- The difference between the potential energy at (2) and at (1) depends on the work done by the force F along the path between (1) and (2).
- The potential at (2) is only uniquely defined if the work done by the force is independent of the path.



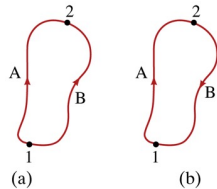
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Conservation of energy. A review.

- If the work is independent of the path, the work around a closed path will be equal to 0 J.
- A force for which the work is independent of the path is called a **conservative force**.
- A force for which the work depends on the path is called a **non-conservative force**.



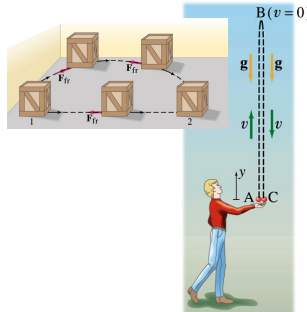
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Conservation of energy. A review.

- Examples of conservative forces:
 - The spring force
 - The gravitational force
- Note: the conservative force is sometimes directed in the direction of motion, sometimes in the opposite direction.
- Examples of non-conservative forces:
 - The kinetic friction force
 - The drag force



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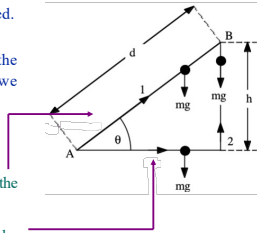
Conservative forces. Path independence.

- The work done by any conservative force depends only on the start and end points, and is independent of the path followed.

- Let's demonstrate this for the gravitational force when we move from A to B.

- We will consider two paths:

- Directly from A to B (along the line connecting A and B).
- Horizontal motion followed by vertical motion.



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Conservative forces. Path independence.

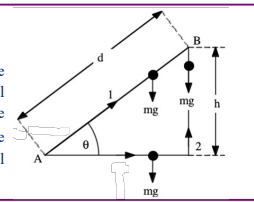
- Path 1 (direct route):

$$W_1 = \vec{F} \cdot \vec{d} = -mgd\sin\theta$$

- Path 2 (D tour):

The work done by the gravitational force when you move from A in the horizontal direction is zero (path and force are perpendicular). The work done by the gravitational force during the vertical segment is equal to

$$W_1 = \vec{F} \cdot \vec{d} = mgh\cos\pi = -mgh$$



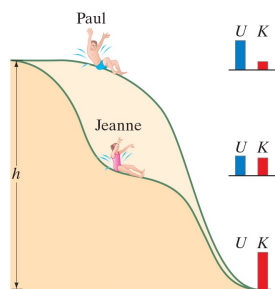
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Conservation of energy.

- Applying conservation of mechanical energy usually simplifies our calculations.
- However, it can only be used if we care only about the relation between the initial state of a system and the final state.
- For example, conservation of mechanical energy will tell us immediately that the two kids on the two slides will have the same velocity at the bottom of the slide. But we can not say anything about their relative time of arrival.



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Conceptual questions.

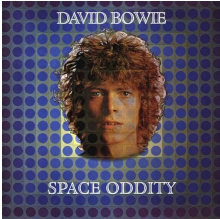
Let's test our understanding of the concepts of mechanical energy and work by working on the following concept problems:



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6 Minute 25 Second Intermission



- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 6 minute 25 second intermission.
- You can:
 - Stretch out.
 - Talk to your neighbors.
 - Ask me a quick question.
 - Enjoy the fantastic music.
 - Solve a WeBWork problem.
 - Go asleep, as long as you wake up in 6 minutes and 25 seconds.



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Always look at the bright side of life!



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Conservation of energy. Dissipative forces.

- When dissipative forces, such as friction forces, are present, mechanical energy is no longer conserved.
- For example, a friction force will reduce the speed of a moving object, thereby dissipating its kinetic energy.
- The amount of energy dissipated by these non-conservative forces can be calculated if we know the magnitude and direction of these forces along the path followed by the object we are studying:

$$\Delta K + \Delta U = W_{NC}$$

where W_{NC} is the work done by the non-conservative forces.

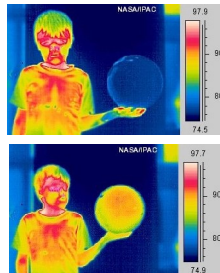
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Conservation of energy. Dissipative forces.

- When dissipative forces are present, some or all of the mechanical energy is converted into "internal" energy.
- The internal energy is usually in the form of heat.



Sharpening a pencil (credit: NASA) Bouncing a ball (credit: NASA)

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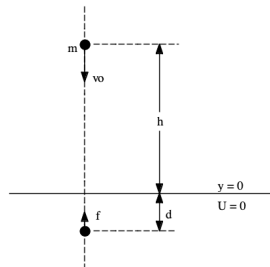
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Problems with dissipative forces. An example.

- A ball bearing whose mass is m is fired vertically downward from a height h with an initial velocity v_0 . It buries itself in the sand at a depth d . What average upward resistive force f does the sand exert on the ball as it comes to rest?

- The initial total mechanical energy of the system is equal to

$$E_i = U_i + K_i = mgh + \frac{1}{2}mv_0^2$$



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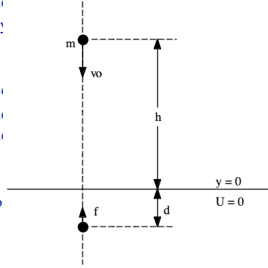
Problems with dissipative forces. An example.

- The final total mechanical energy of the system is equal to just the potential energy of the bearing which is equal to

$$E_f = -mgd.$$
- Mechanical energy is not conserved since the friction force dissipates some of the mechanical energy. The work done by the friction force is equal to

$$W_f = -fd$$
- The change in the mechanical energy of the system is

$$\Delta E = E_f - E_i = -mgd - mgh - \frac{1}{2}mv_0^2$$



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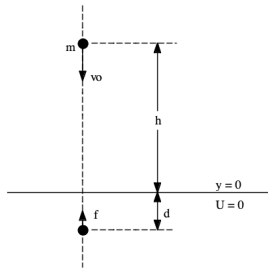
Problems with dissipative forces. An example.

- The change in the mechanical energy of the system must be equal to the work done by the friction force (assuming this is the only dissipative force acting on the system):

$$-fd = -mg(h + d) - \frac{1}{2}mv_0^2$$

- This relation can now be used to calculate the magnitude of the friction force f :

$$f = mg \frac{h}{d} + \frac{1}{2} \frac{mv_0^2}{d}$$



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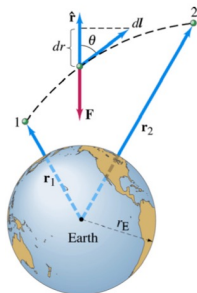
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One final application. The gravitational potential energy.

- In our discussion so far we have taken the gravitational potential energy to be equal to mgh .
- This is correct when we are very close to the surface of the Earth, but not correct when we are a few miles from the surface of the earth.
- The work done by the gravitational force when we move an object from (1) to (2) is equal to

$$W = GmM_E \left(\frac{1}{r_2} - \frac{1}{r_1} \right)$$



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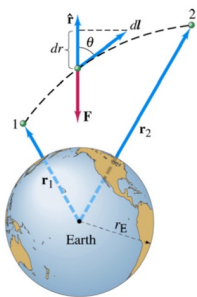
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One final application. The gravitational potential energy.

- The potential energy difference between position (1) and (2) is thus equal to

$$U_2 - U_1 = -W = GmM_E \left(-\frac{1}{r_2} + \frac{1}{r_1} \right)$$

- It is common to choose the gravitational potential energy to be equal to 0 J at infinity. With the choice, the potential energy at (1) will be equal to

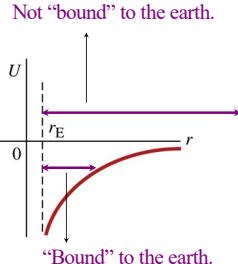
$$U_1 = -G \frac{mM_E}{r_1}$$


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One final application. The gravitational potential energy.

- Consider an object on the surface of the earth with a kinetic energy $K(r_E)$. The total mechanical energy of the object is $U(r_E) + K(r_E)$.
- If $U(r_E) + K(r_E) < 0$ then there will be a distance r where $U(r) = U(r_E) + K(r_E)$. At that distance $K(r) = 0$ J. **The object can not escape!**
- If $U(r_E) + K(r_E) > 0$ then at every distance r , $K(r) > 0$ J. **The object can escape!**
- The limiting case occurs when $U(r_E) + K(r_E) = 0$. The velocity for which this is case, it called the **escape velocity**. For the earth, this velocity is 11,200 m/s.



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Done for today! Next week: conservation of linear momentum.



1986 is an actual fly-by during deployment of the Nuclear Attack Class SSBN *Sumner*. The pilot was grounded for 30 days, but for this picture and thinking it was worth it. "A-6E"

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