Physics 121.
Tuesday, February 26, 2008.

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

Course information.
Exam # 1.

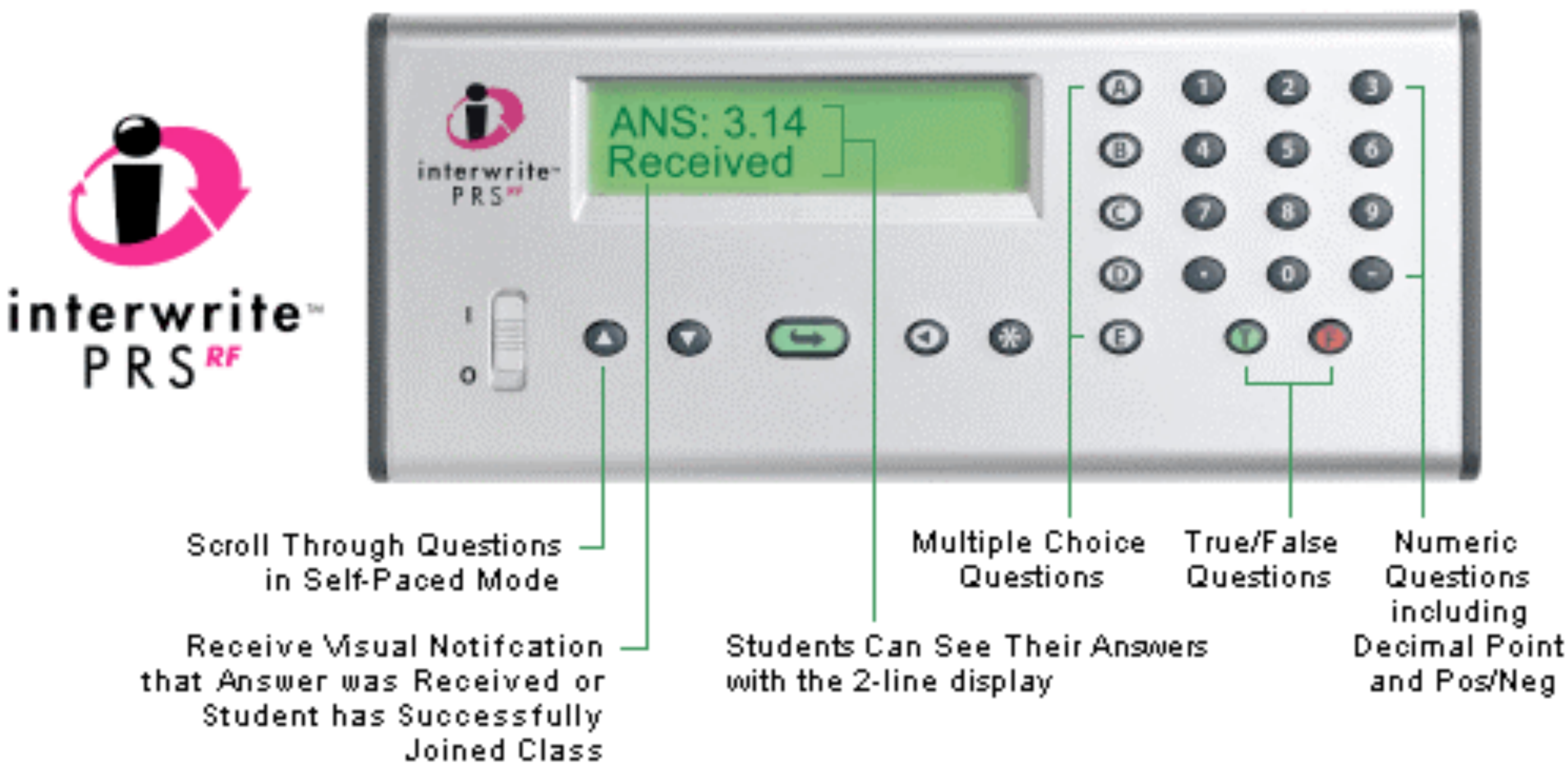
- On Thursday February 28 between 8 am and 9.30 am the first midterm exam of Physics 121 will be held:
  - Material covered: Chapters 1 - 6 of our text book.
  - Location: Hubbell.
- There will be a normal lecture after the exam (at 9.40 am in Hoyt).
- A Q&A session on the material covered on exam # 1 will take place on Tuesday evening 2/26 between 9 pm and 11 pm in Hoyt (location needs to be confirmed).
- There will be extra office hours on Tuesday 2/26 and Wednesday 2/28:
  - Tuesday: 1 - 4 pm (B&L 304) + 5 - 9 pm (POA library, 2 TAs)
  - Wednesday: 1 - 3 pm (B&L 304) + 2.45 - 4.45 pm (POA library, 1 TA) + 7 - 10 pm (2 - 3 TAs)

Course information.
Exam # 1.

- During workshops on Tuesday 2/26 and Wednesday 2/27, the focus will be exam # 1. You can attend any (or all) workshops on these days. Bring your questions!
- There will be no workshops and office hours on Thursday 2/28 and Friday 2/29.
- You will receive the exam back during workshop during the week of March 3.
- Any corrections to the grades of your grade can only be made by me, not by your TAs.
- The TAs will not see the exam until you see it.

Physics 121.
Quiz lecture 11.

- The quiz today will have 3 questions.



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:

$$E = K + U$$

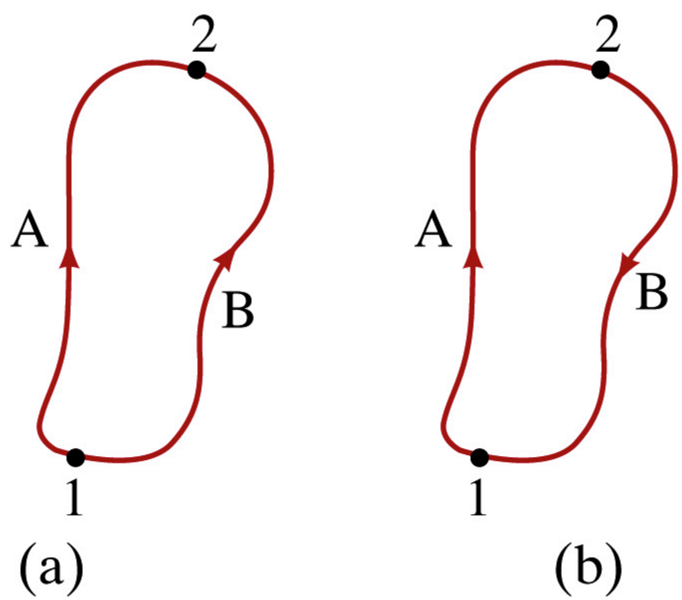
- If the total mechanical energy is constant, we must require that $\Delta E = 0$, or

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

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

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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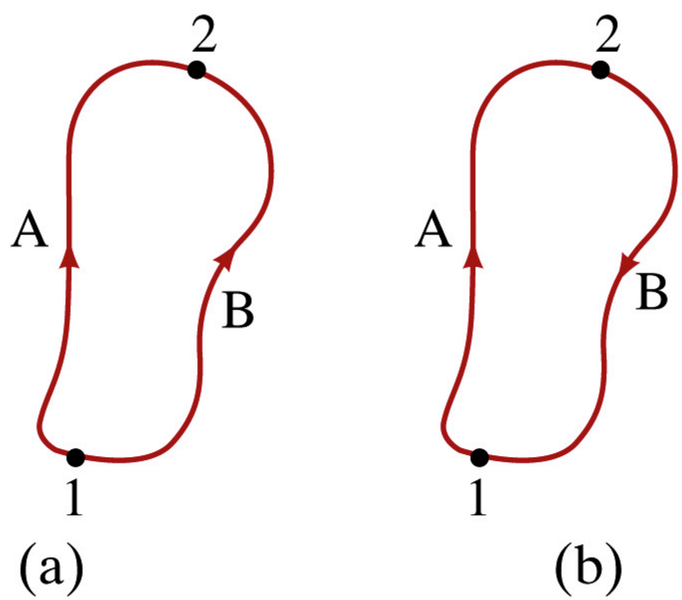
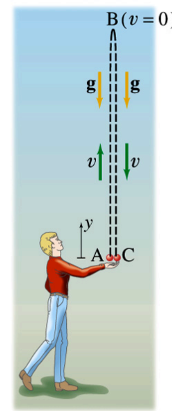
Conservation of energy. A review.

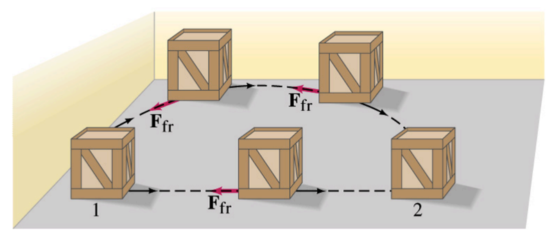
- If the work is independent of the path, the work around a closed path will be equal to 0 J.
- A force for which the work is independent of the path is called a **conservative force**.
- A force for which the work depends on the path is called a **non-conservative force**.



Conservation of energy.
A review.

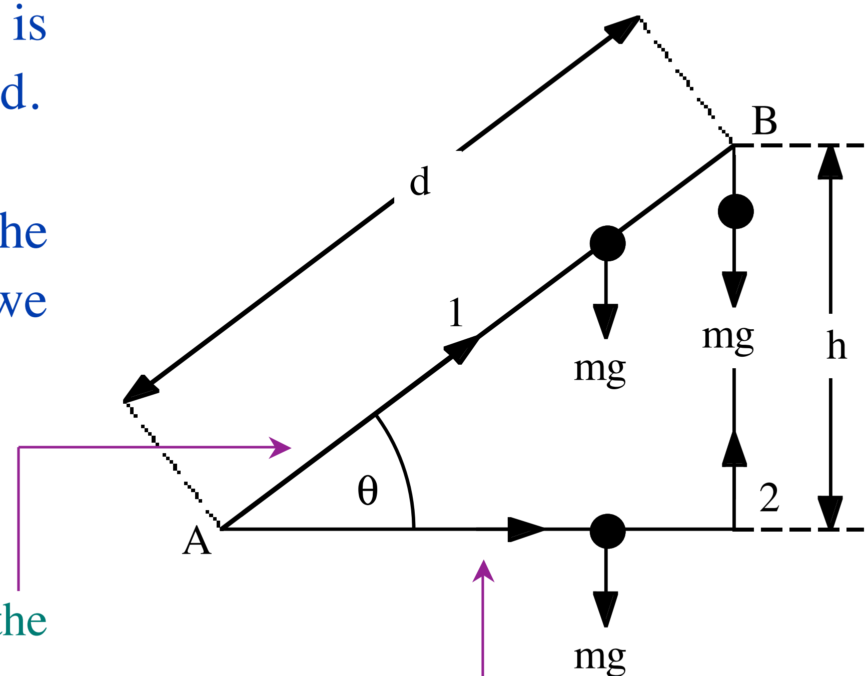
- Examples of conservative forces:
  - The spring force
  - The gravitational force
- Note: the conservative force is sometimes directed in the direction of motion, sometimes in the opposite direction.
- Examples of non-conservative forces:
  - The kinetic friction force
  - The drag force





Conservative forces. Path independence.

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



Conservative forces. Path independence.

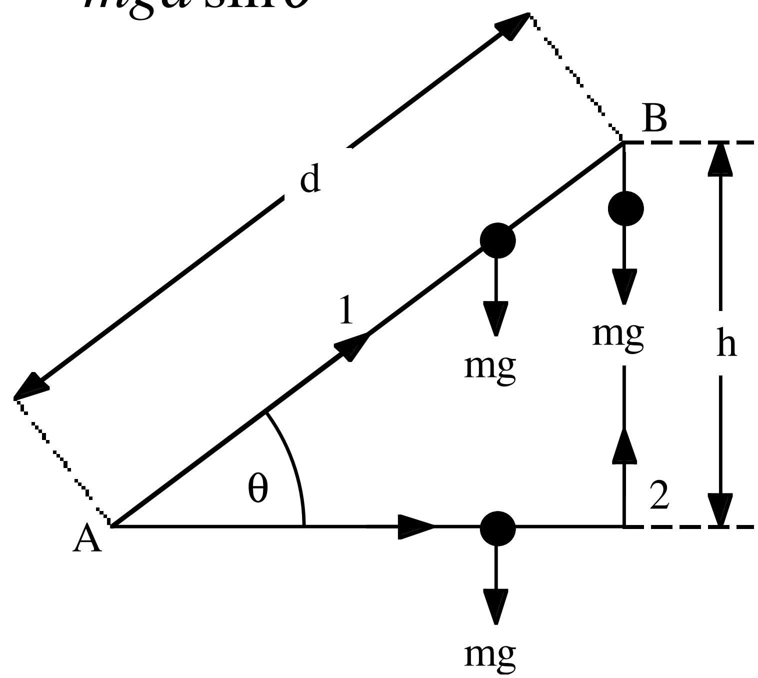
- Path 1 (direct route):

$$W_1 = \vec{\mathbf{F}} \bullet \vec{\mathbf{d}} = mgd\cos\left(\frac{1}{2}\pi + \theta\right) = -mgd\sin\theta$$

- Path 2 (D tour):

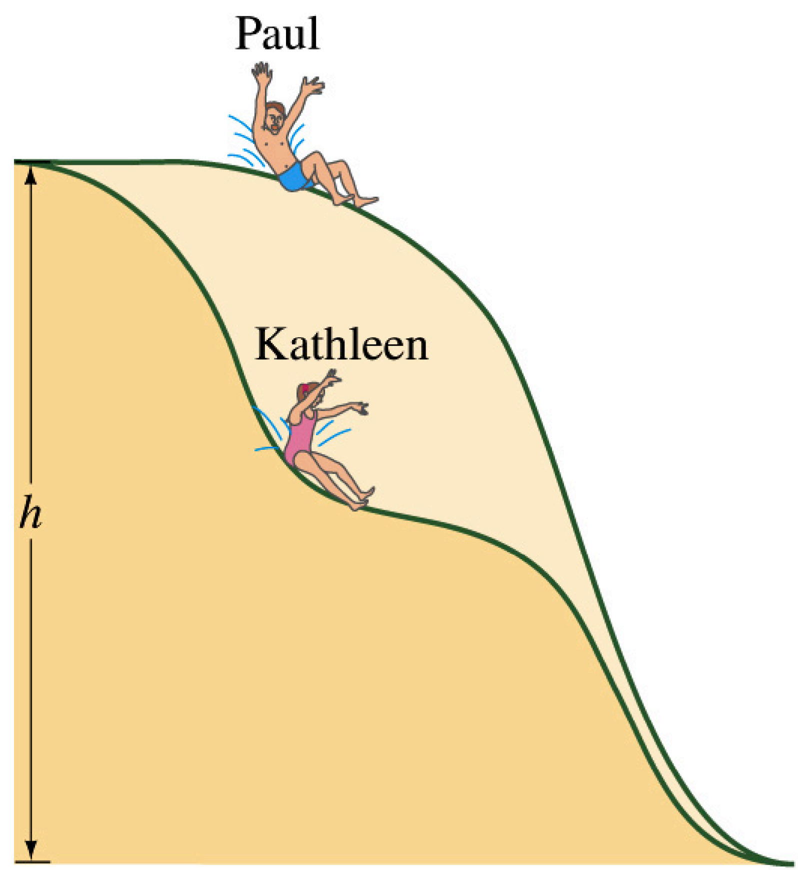
The work done by the gravitational force when you move from A in the horizontal direction is zero (path and force are perpendicular). The work done by the gravitational force during the vertical segment is equal to

$$W_1 = \vec{\mathbf{F}} \bullet \vec{\mathbf{d}} = mgh\cos\left(180^\circ\right) = -mgd\sin\theta$$



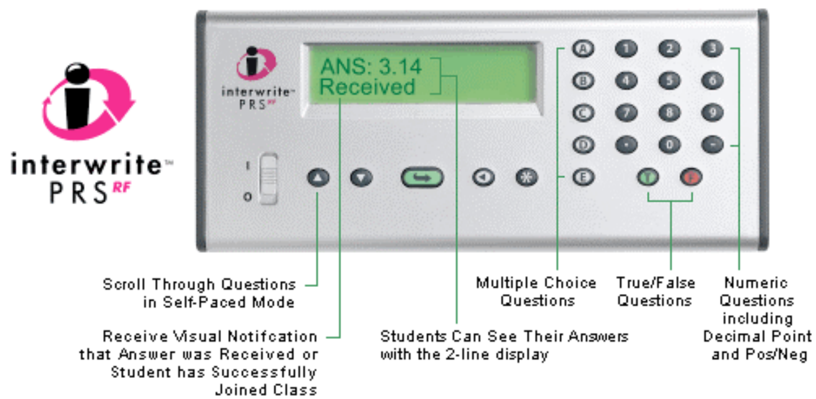
Conservation of energy. A review.

- 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.



Conservation of energy.
A review.

- Let's test our understanding of the concepts of mechanical energy and work by working on the following concept problems:
  - Q11.1
  - Q11.2
  - Q11.3
  - Q11.4



- Note: for each of these 4 problems I like to get just your opinion, not a group opinion.

Conservation of energy. Dissipative forces.

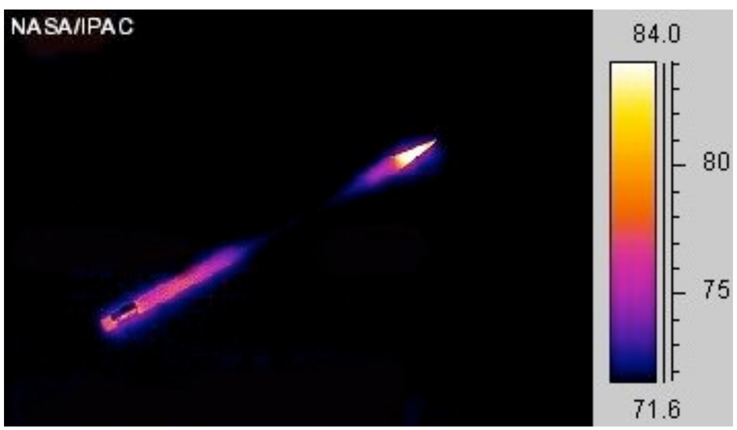
- When dissipative forces, such as friction forces, are present, mechanical energy is no longer conserved.
- For example, a friction force will reduce the speed of a moving object, thereby dissipating its kinetic energy.
- The amount of energy dissipated by these non-conservative forces can be calculated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

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

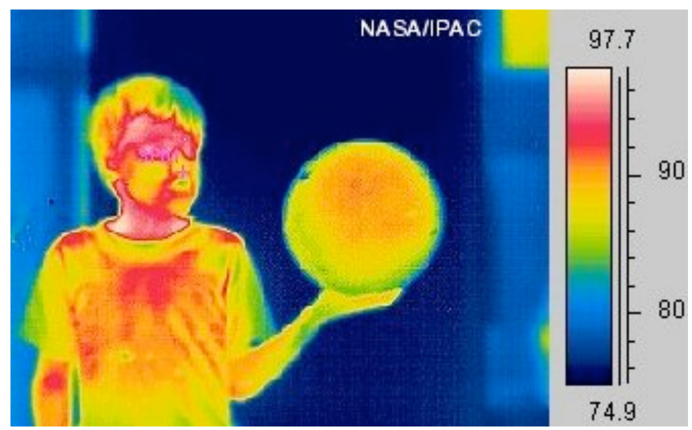
where W_{NC} is the work done by the non-conservative forces.

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)



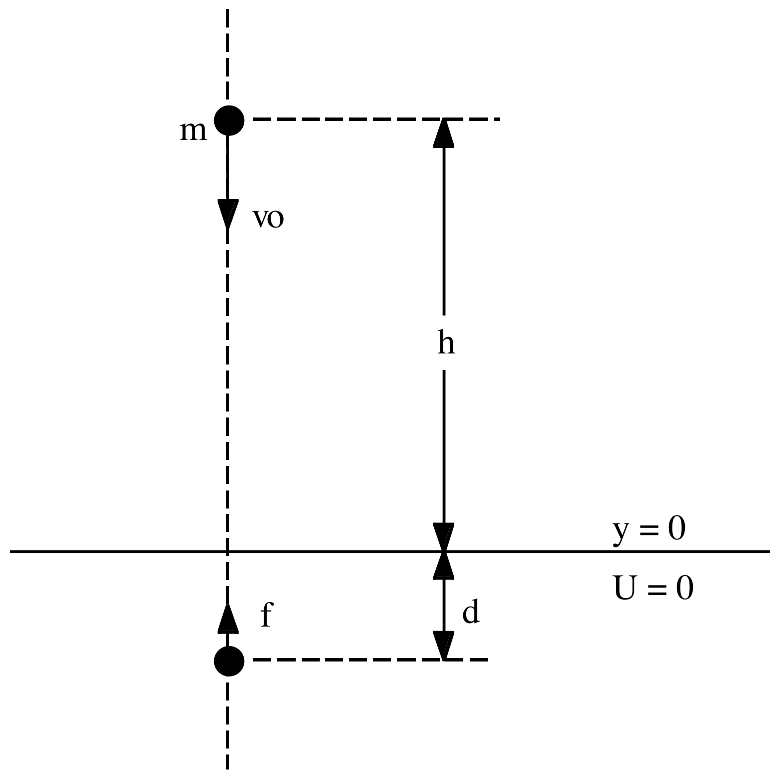
Bouncing a ball (credit: NASA)

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?

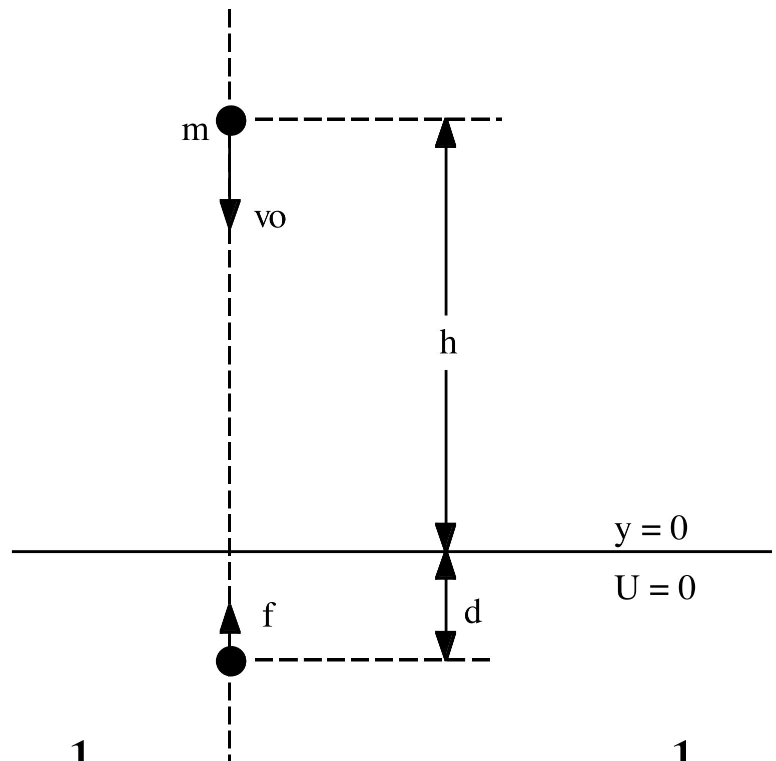
- The initial total mechanical energy of the system is equal to

$$E_i = U_i + K_i = mgh + \frac{1}{2} m {v_0}^2$$



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



$$\Delta E = E_f - E_i = -mgd - mgh - \frac{1}{2}m{v_0}^2 = -mg\left(h+d\right) - \frac{1}{2}m{v_0}^2$$

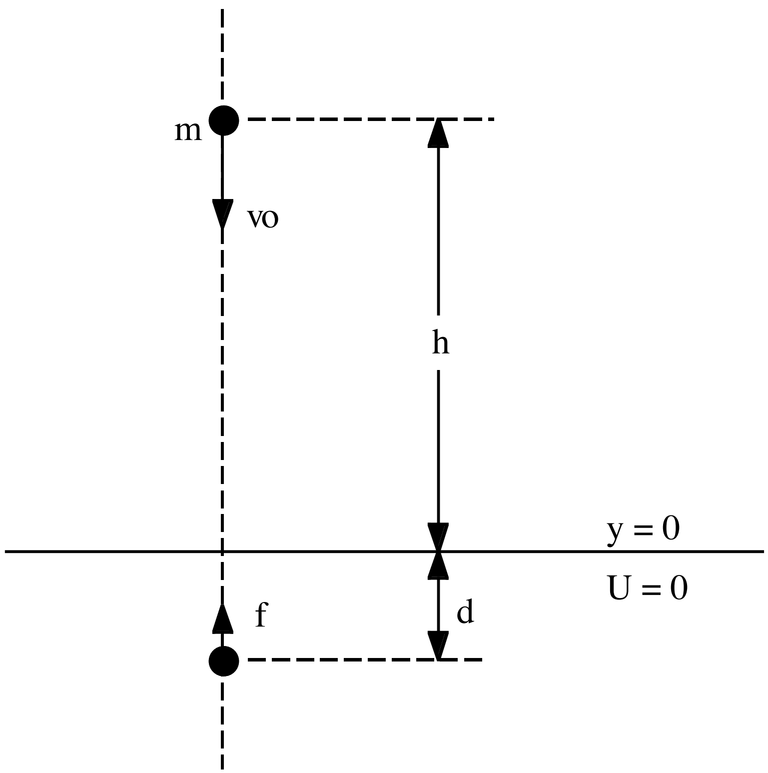
Problems with dissipative forces. An example.

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

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

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

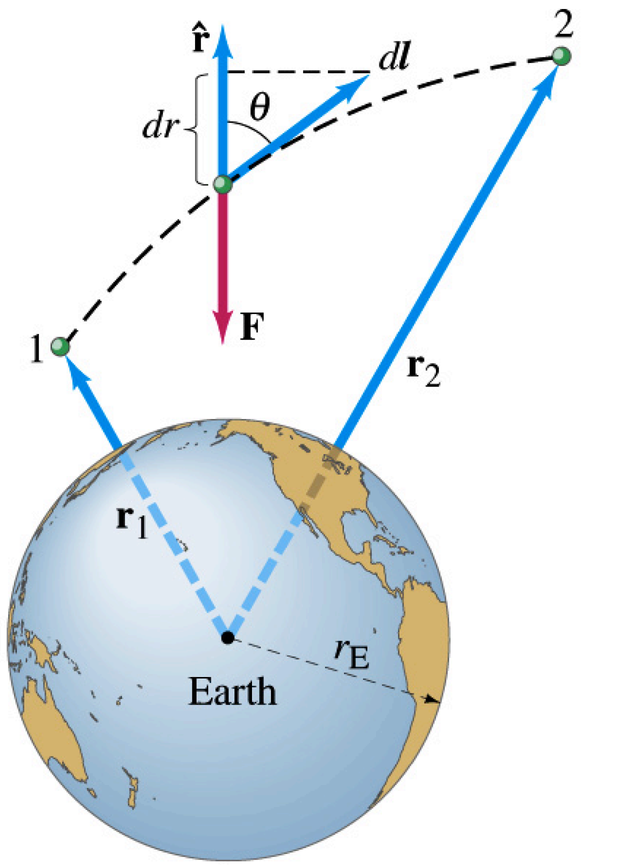
$$f = mg + mg\frac{h}{d} + \frac{1}{2}\frac{mv_0^{\;2}}{d}$$



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

$$W = GmM_E(1/r_2 - 1/r_1)$$



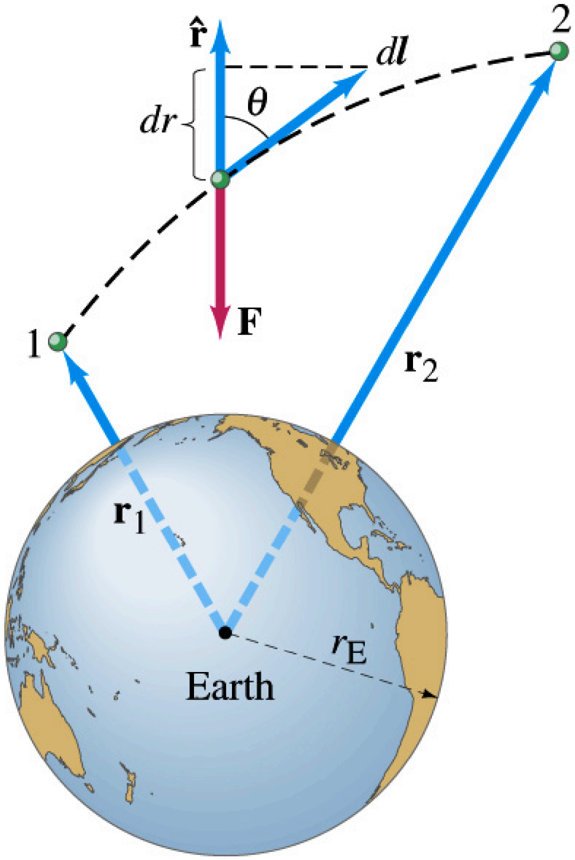
One final application. The gravitational potential energy.

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

$$U_2 - U_1 = -W = GmM_E(-1/r_2+1/r_1)$$

- 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

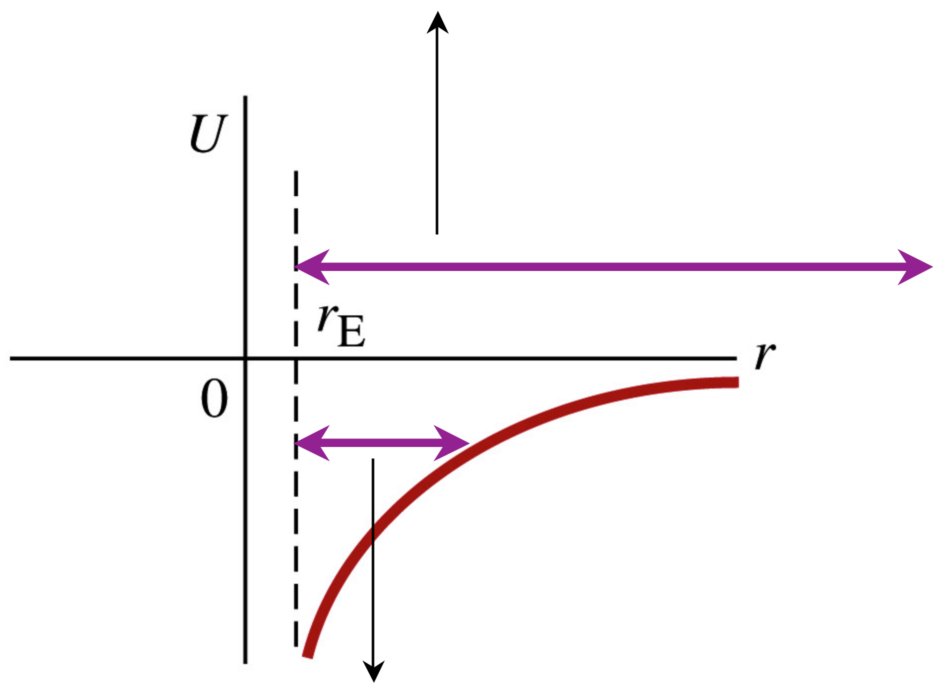
$$U_1 = -GmM_E/r_1$$



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 es**cape velocity**. For the earth, this velocity is 11,200 m/s.

Not "bound" to the earth.



"Bound" to the earth.

Done for today!
Thursday: conservation of linear momentum.