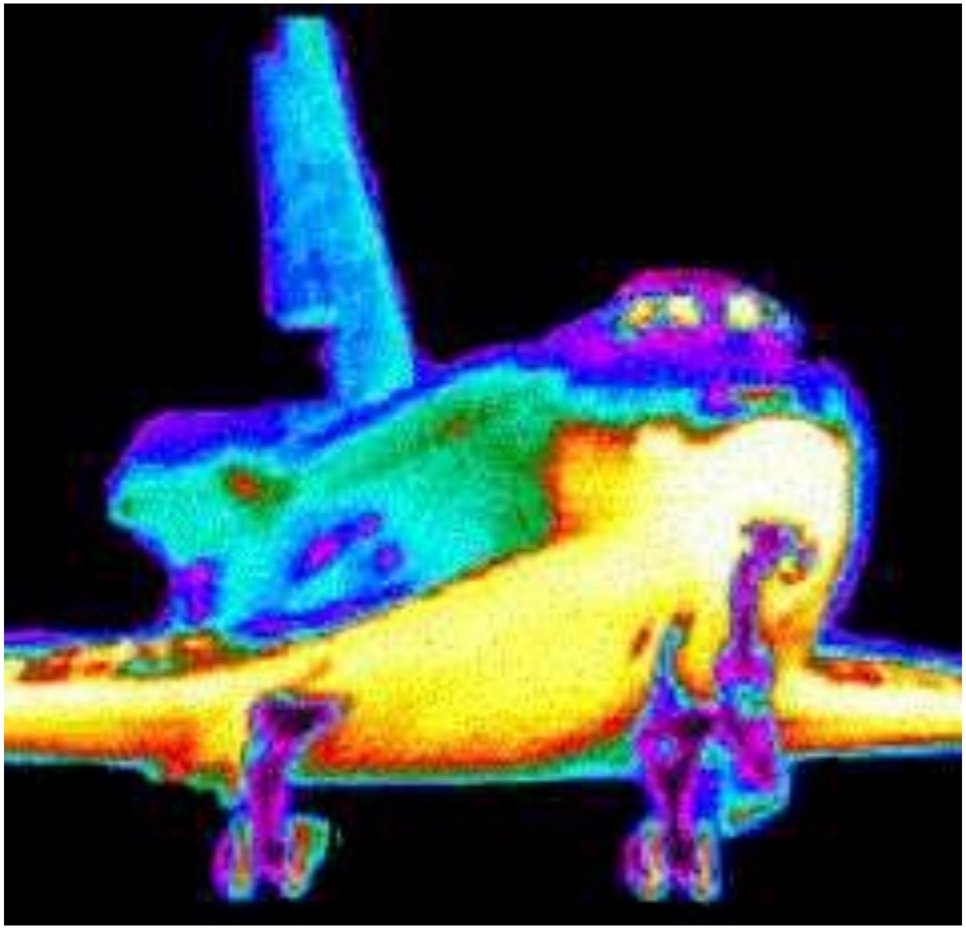
Physics 141.
Lecture 10.



This object is not in a state of thermal equilibrium.

Good to know for Exam # 2: Yankees are AL East Champions for the 21st time.

https://www.youtube.com/watch?v=9aYhxISaAMA

Outline.

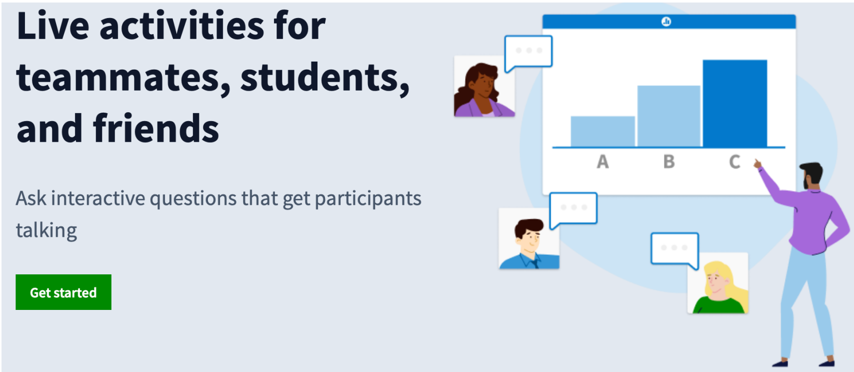
- Course information:
  - Exam # 1.
  - Laboratory.
  - Homework.
- Quiz.
- Complete the discussion of Chapter 6:
  - Review of the definition of potential energy.
  - Using the energy principle when non-conservative forces are present.

Course Information.

- Exam # 1:
  - Any changes in the grading of the exam can only be made me.
  - Please me provide today (10/1) with your exam and a note describing why you feel you deserve more points.
- Laboratory:
  - Laboratory experiment # 3 is scheduled for Monday October 7.
- Homework:
  - Homework set # 4 is due on Friday 10/4 at 12 pm (noon).
  - Homework set # 5 is due on Friday 10/11 at 12 pm (noon).

Quiz lecture 10.
PollEv.com/frankwolfs050

- The quiz today will have four questions.
- I will collect your answers electronically using the Poll Everywhere system.
- The answers for each question will be entered in sequence (first 60 s for question 1, followed by 60 s for question 2, etc.).



The energy principle ($Q = 0$). Multi-particle systems.

- When we are dealing with multi-particle systems we have to separate the forces acting on the system into two groups:
  - **Internal forces**: forces that act between the particles that make up the system.
  - **External forces**: forces that are generated due to interactions between the system and its surroundings.

- The opposite of the work done by the internal forces on the system is called the **potential energy** of the system:

$$\sum_i \Delta E_i - (W_{int}) = \sum_i \Delta E_i + \Delta U = W_{ext}$$

- If our system is a rigid system (fixed relative positions of the particles), the potential energy associated with the internal forces is constant and $\Delta U = 0$.

The energy principle ($Q = 0$). Multi-particle systems.

- When we apply our equation for the change in the energy of our system, we have to realize that how we treat forces depends on how we define out system.

$$\sum_i \Delta E_i - (W_{int}) = \boxed{\sum_i \Delta E_i + \Delta U} = W_{ext}$$

Change in energy of our system

Choice of Systems.

- Consider an object in free fall close to the surface of the Earth.

- If our system consists of the object and the Earth, **the gravitational force is an internal force and we will include it in the calculation of the potential energy of our system.** Since the relative position of the object and the Earth will change, the change in U will not be equal to 0.

- If our system consists of the object only, **the gravitational force is an external force and will be included in our calculation of the work associated with external forces**.

Calculating the potential energy *U*. One dimension.

- Per definition, the change in potential energy is related to the work done by the force:

$$\Delta U = -W = -\int_{x_0}^{x} F(x)dx$$

- The potential energy at *x* can thus be related to the potential energy at a point x_0:

$$U(x) = U(x_0) + \Delta U = \boxed{U(x_0)} - \int_{x_0}^{x} F(x)dx$$

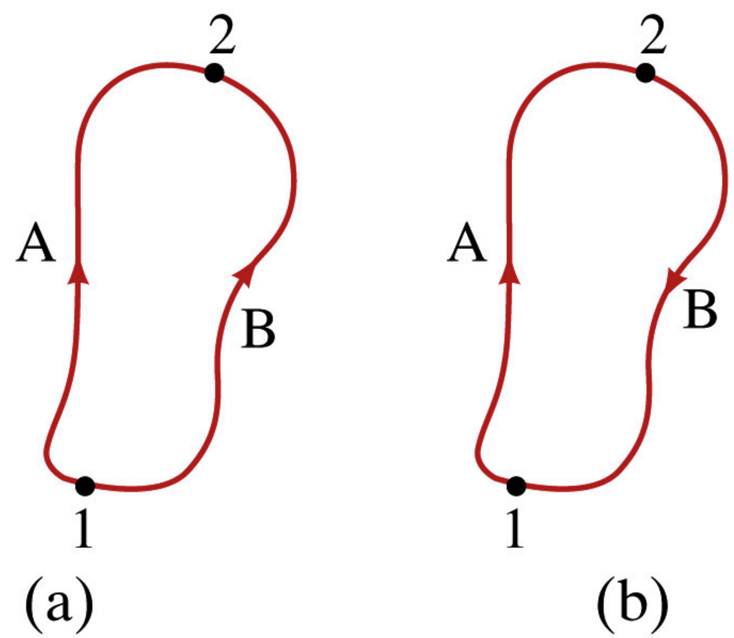
U(*x*) is only uniquely defined if integral is path independent.

Potential at reference position.

Reference position.

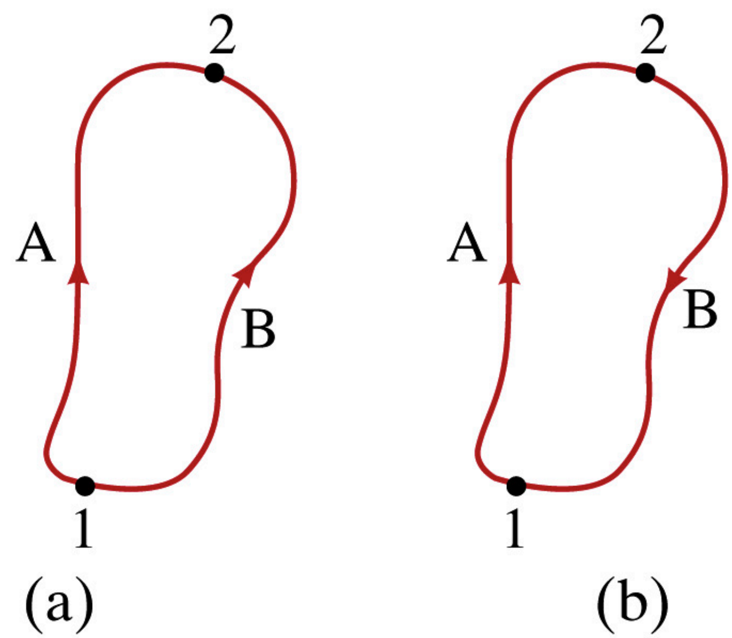
Calculating the potential energy. Path dependence.

- 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).
- But ……. we can get from (1) to (2) via path A and via path B. In order to uniquely define the potential at (2) the work done must only depend on the start and end point, and not on the path followed.



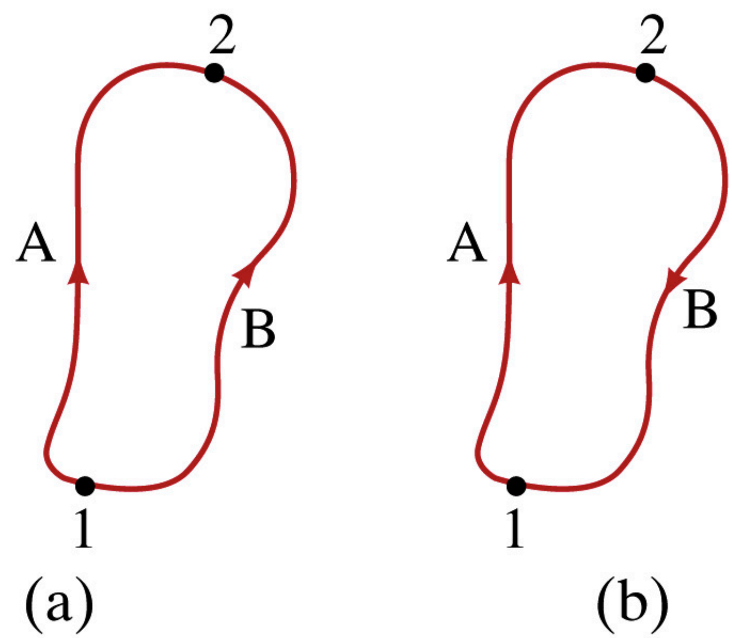
Calculating the potential energy. Path dependence.

- The work done must only depend on the start and end point, and not on the path followed.
- This is not true for all forces. For example, the work done by the friction force is always negative. If the friction force is constant in magnitude, the work done by the friction force depends on the path length and is thus path dependent.



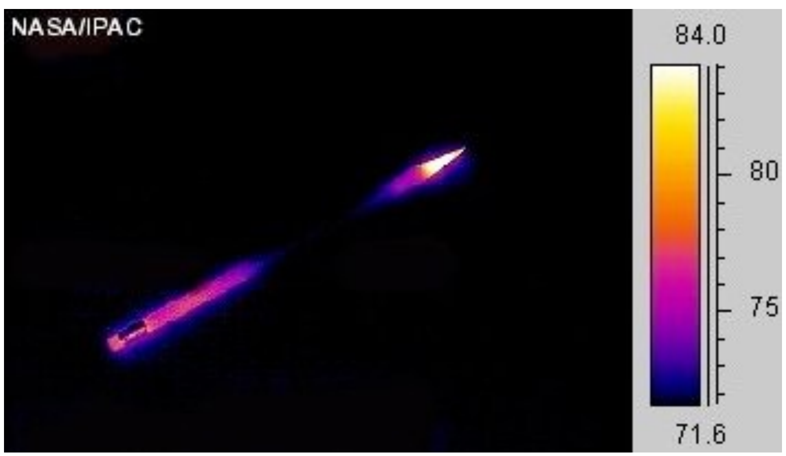
Calculating the potential energy. Conservative and non-conservative forces.

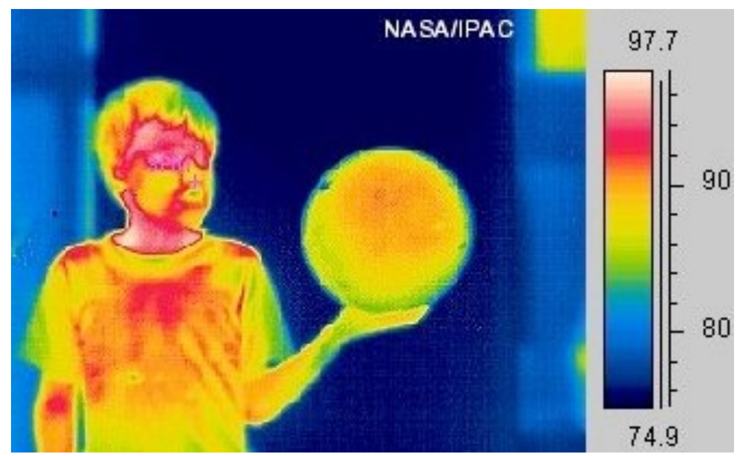
- If the work is independent of the path, the work around a closed path will be equal to 0 J.
- A force for which the work is independent of the path is called a **conservative force**.
- A force for which the work depends on the path is called a **non-conservative force**.



Conservation of energy.
Dissipative forces.

- When dissipative forces are present, some or all of the kinetic energy is converted into "internal" energy (of the system and its surroundings)
- The internal energy is usually in the form of heat.





Sharpening a pencil (credit: NASA)

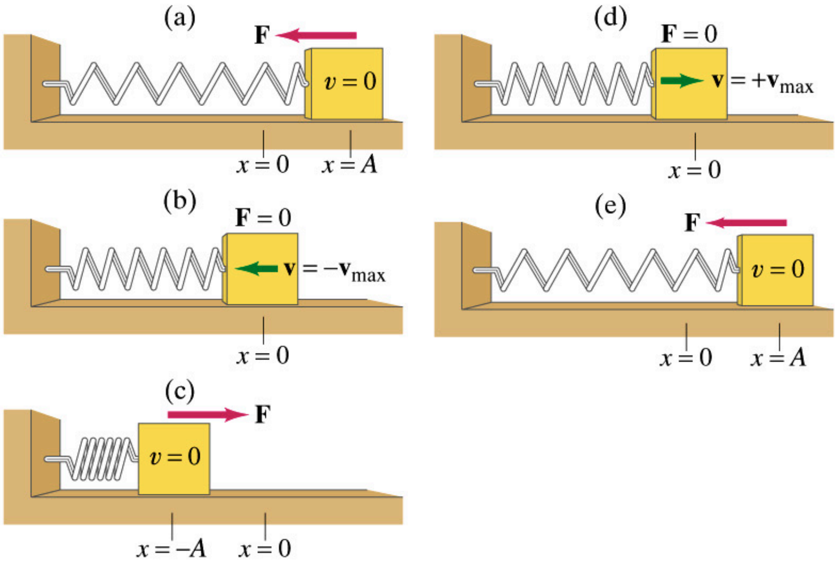
Bouncing a ball (credit: NASA)

Calculating the potential energy. The potential energy of a spring.

- Consider the work done by a spring when we move a block from its equilibrium position to a position $x = A$.
- During this displacement, the force is pointed in a direction opposite to the displacement, and the work done is negative.
- The total work done is equal to

$$W = -\int_0^A kx dx = -\frac{1}{2}kA^2$$

- The potential energy of the spring is thus $U(x) = -W = \frac{1}{2}kx^2$.

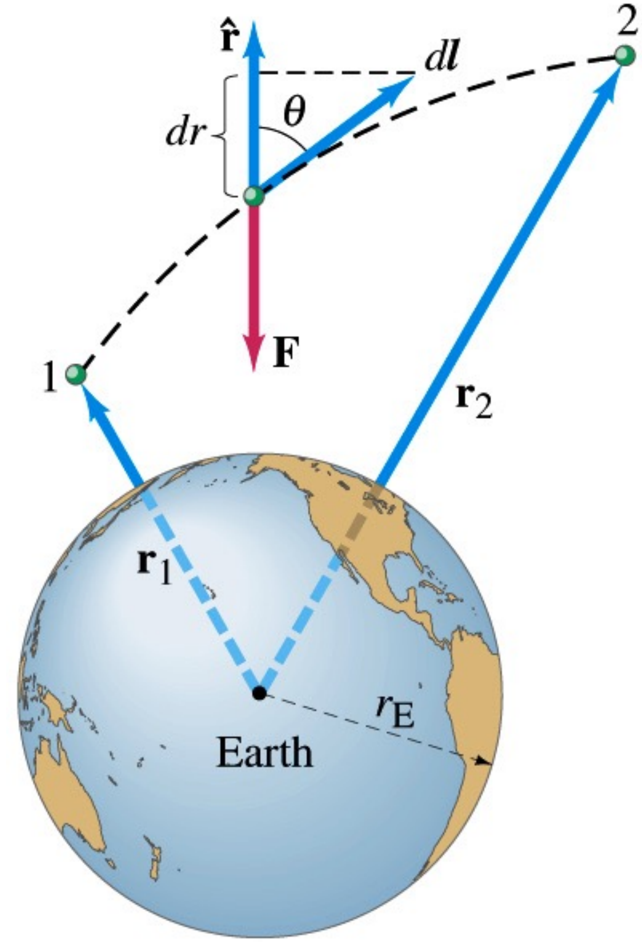


Note: reference position is the rest position of the spring. The potential energy at this position is 0 J.

Calculating the potential energy. The gravitational potential energy.

- In our discussion so far, we have taken the gravitational potential energy to be equal to *mgh*.
- This is approximately 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 position 1 to position 2 is equal to

$$W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r} = -GmM\left\{\frac{1}{r_1} - \frac{1}{r_2}\right\}$$



Note: reference position is at infinity. The potential energy at this position is 0 J.

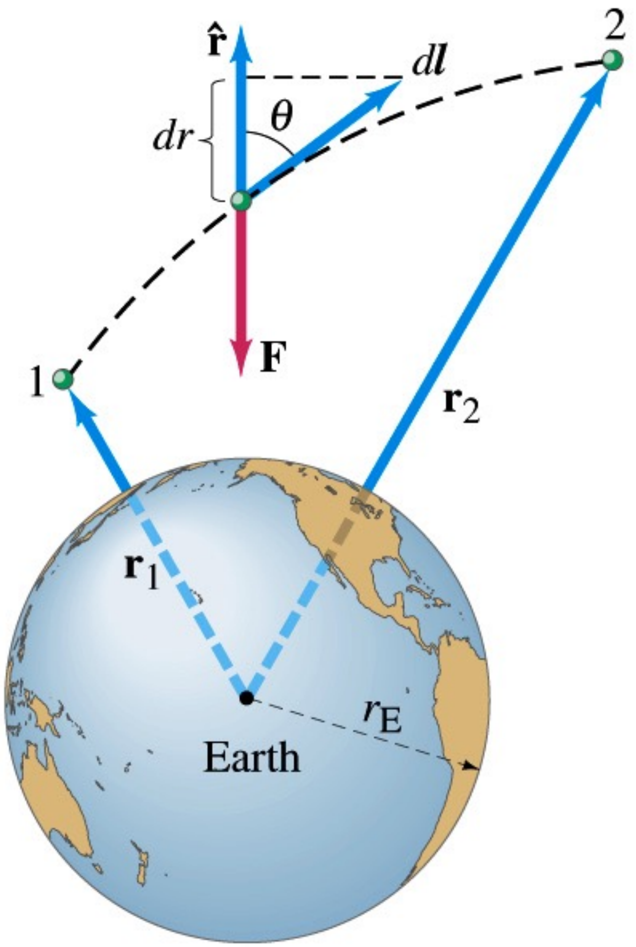
Calculating the potential energy. The gravitational potential energy.

- The potential energy at position 2 is thus equal to

$$U(\vec{r}_2) = U(\vec{r}_1) + GmM\left\{\frac{1}{r_1} - \frac{1}{r_2}\right\}$$

- Choosing our reference point (position 1) at infinity and setting the potential energy at this position to 0 J, we find that the potential energy at position 2 is equal to

$$U(\vec{r}_2) = -G\frac{mM}{r_2}$$



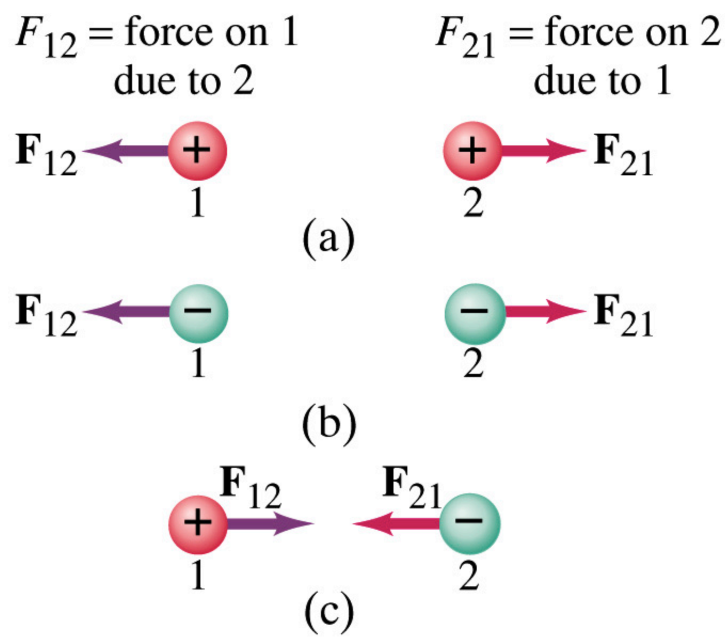
Calculating the potential energy. The electric potential energy.

- The electric force between two charged particles is equal to

$$\vec{F}_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}^2}\hat{r}_{12}$$

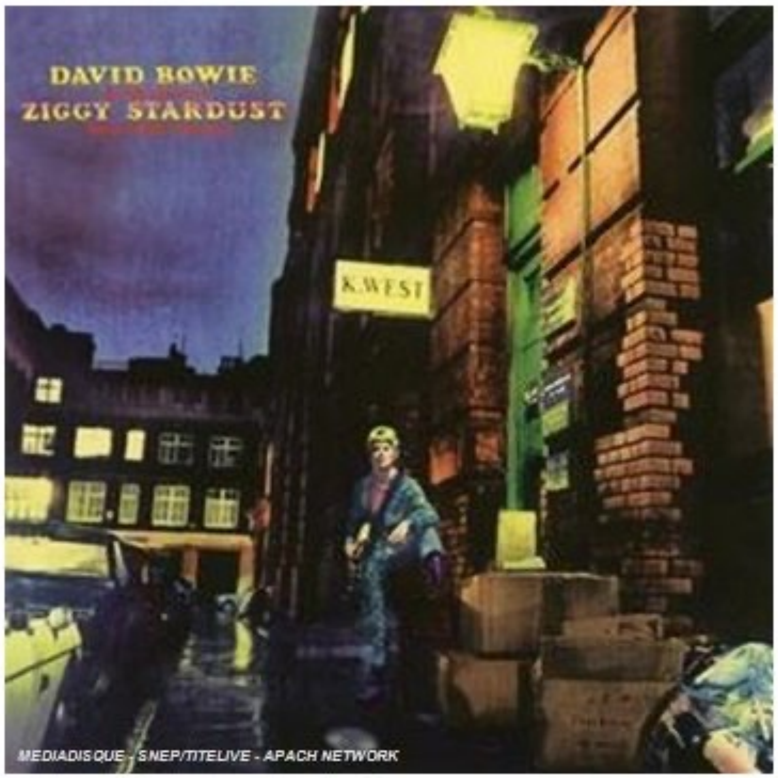
- The electric potential energy required to assemble a pair of charges can be found in the same way we determine the gravitational potential energy. We find that

$$U_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$



Note: reference position is at infinity. The potential energy at this position is 0 J.

3 Minute 13 Second Intermission



- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 13 second intermission.

- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.
  - Go asleep, as long as you wake up in 3 minutes and 13 seconds.

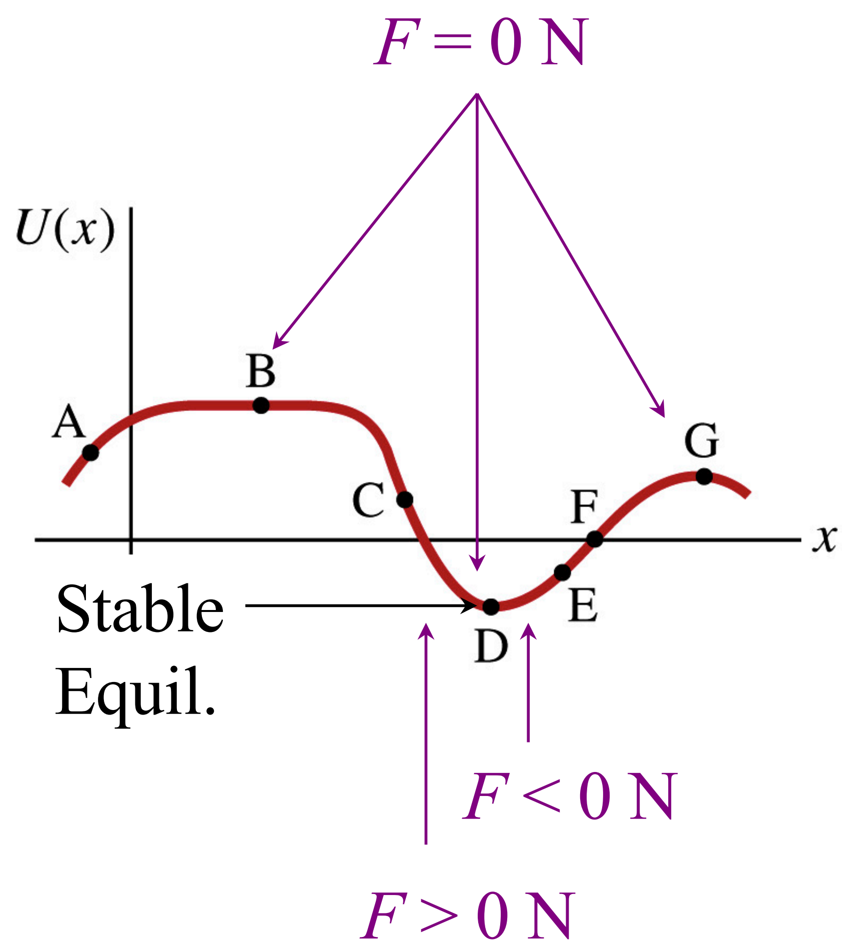
Potential energy in one dimension.

- The potential energy is directly related to the force acting on the object.
  - If we know the force, we can calculate the change ΔU:

$$\Delta U = -W = -\int_{x_0}^{x} F(x)dx$$

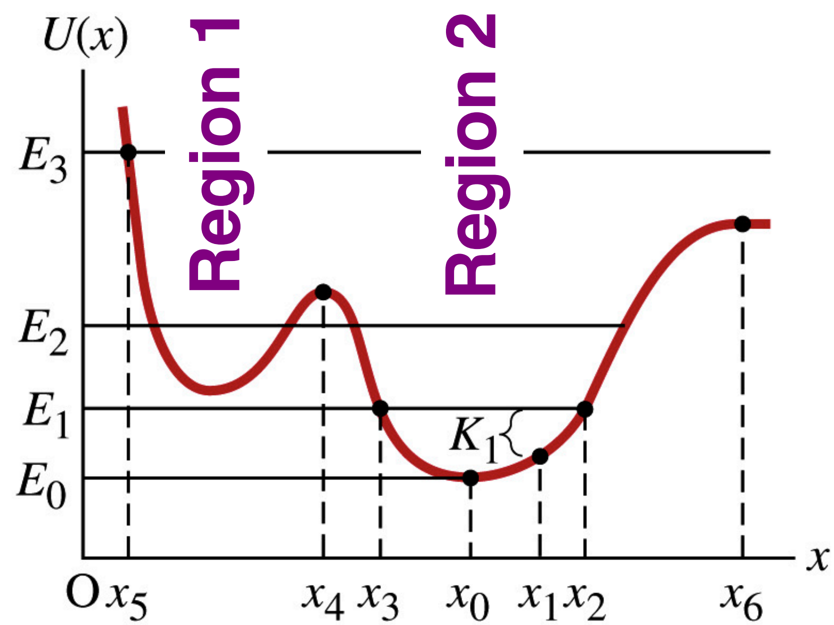
  - If we know the change dU, we can calculate the force:

$$F(x) = -\frac{dU}{dx}$$



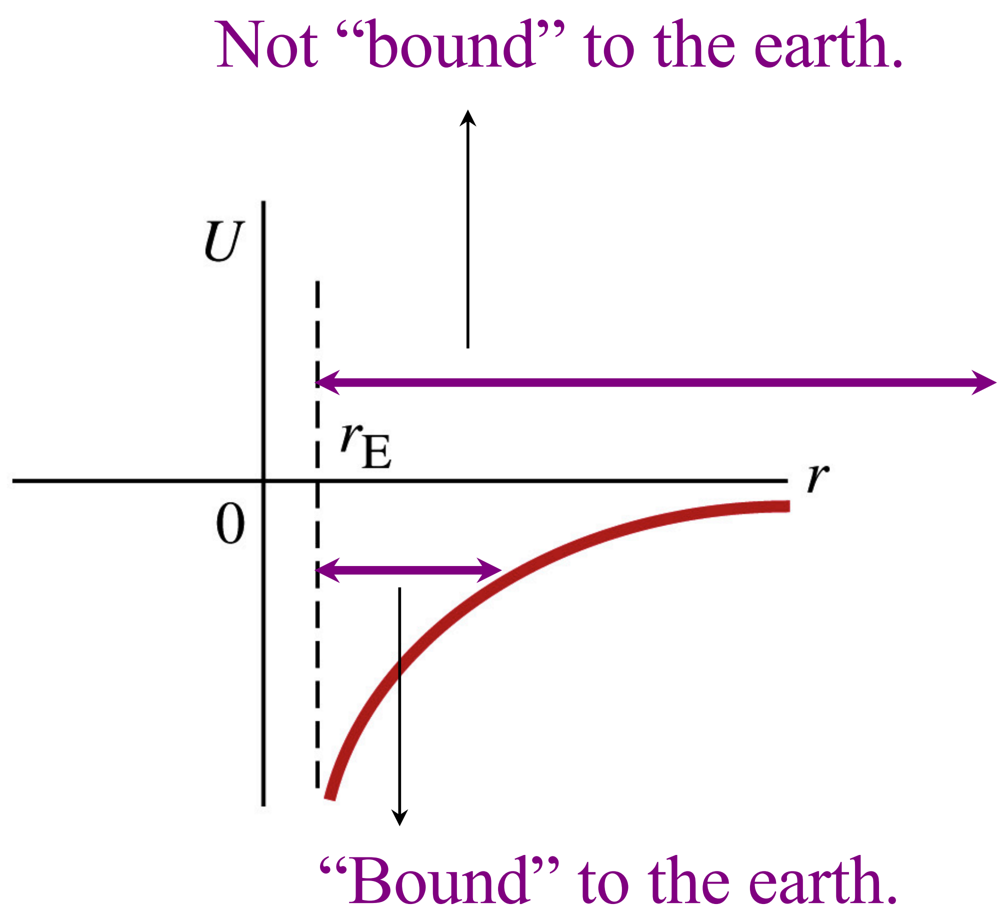
Potential energy distributions. Great tools to study system dynamics.

- Consider a particle that can move in a region where we know the potential energy:
  - If the energy of the particle is E_1 it can can move between x_1 and x_3.
  - If the energy of the particle is E_3, it can move in the entire $x > x_5$ region.
  - If the energy of the particle is E_2, its motion is restricted to two regions (region 1 and region 2) and no motion from region 1 to region 2, and vice-versa, is permitted.

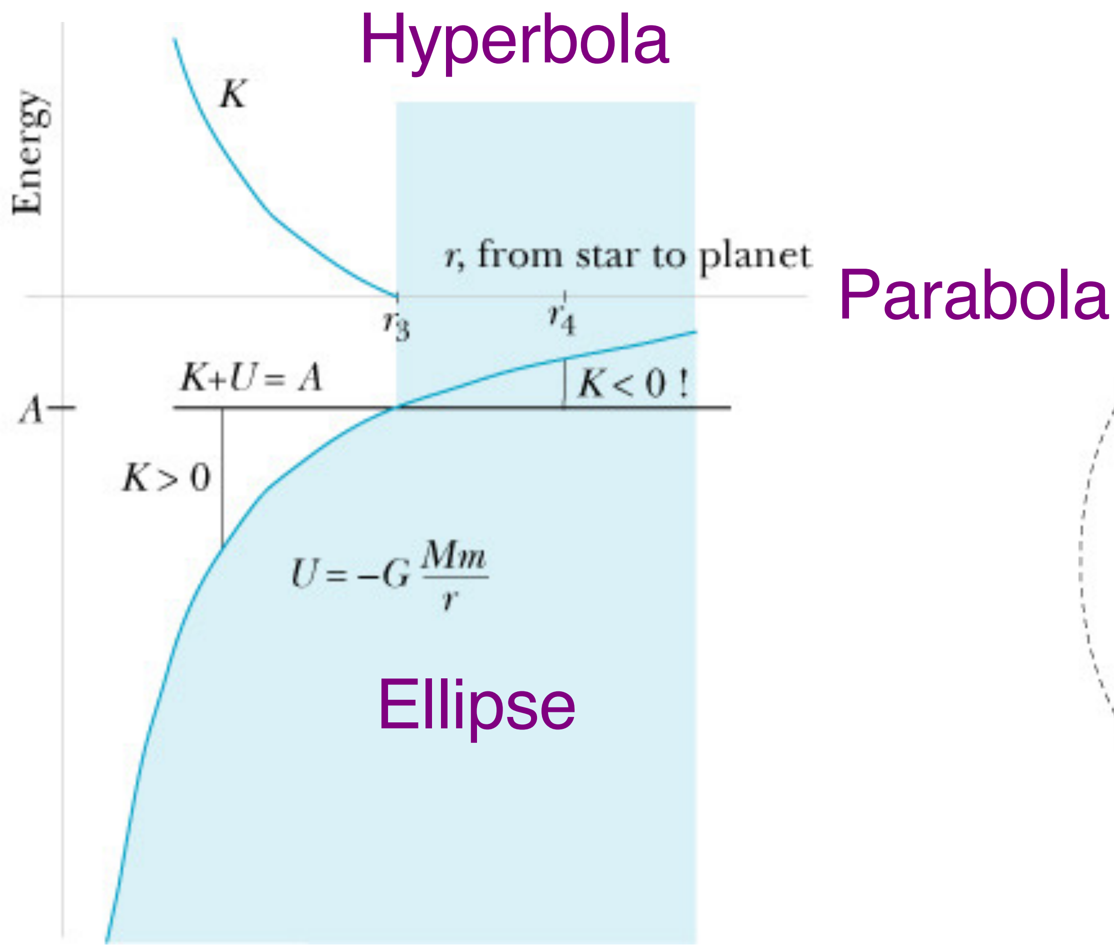


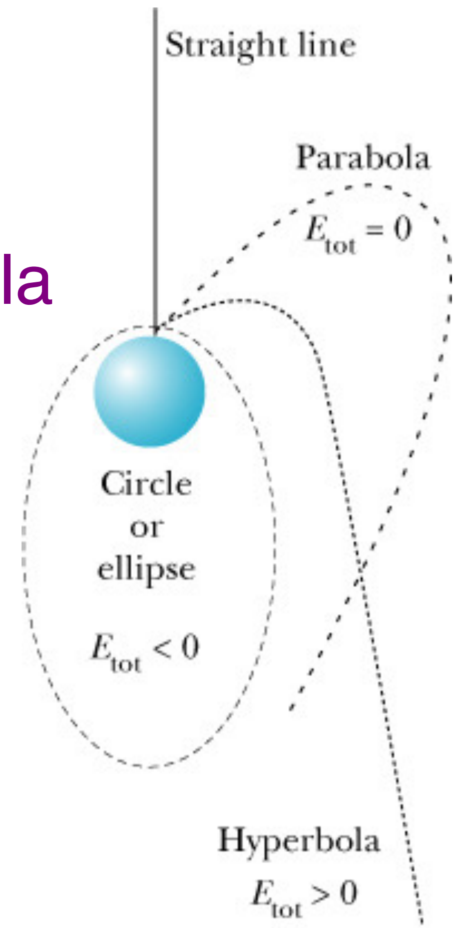
Potential energy distributions. The gravitational potential energy.

- Consider an object on the surface of the earth with a kinetic energy $K(r_E)$. The total 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.



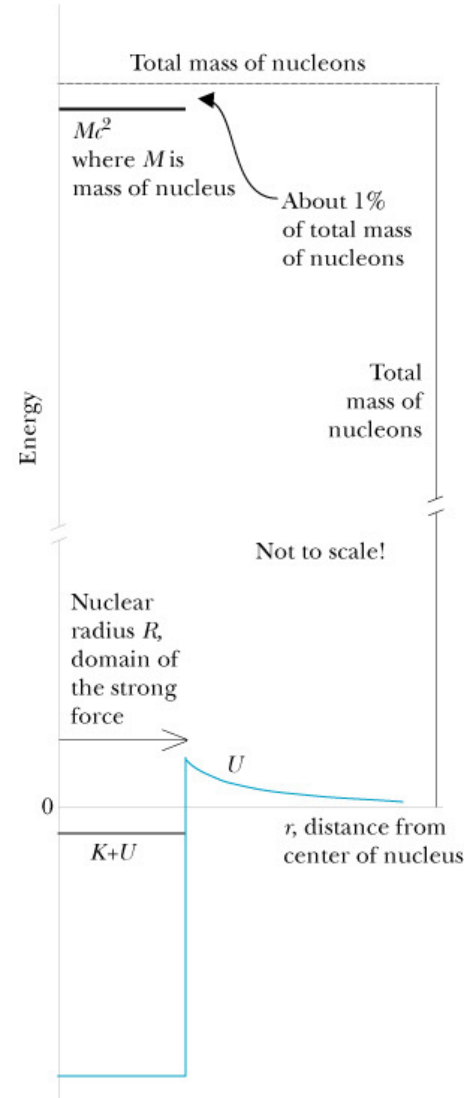
Potential energy distributions. Predicting stability.





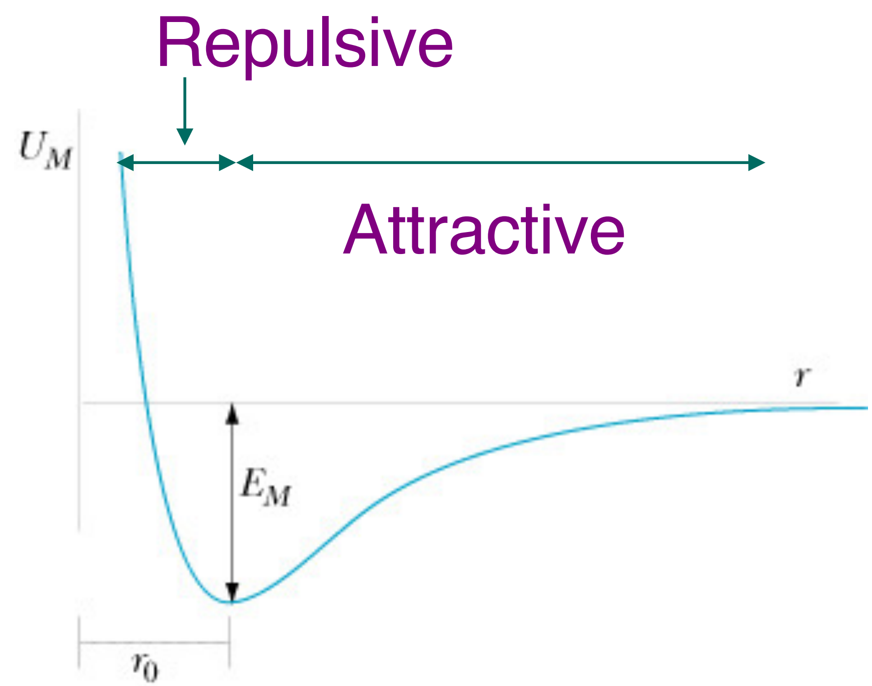
Potential energy distributions. Predicting stability.

- The force between a proton and a nucleus is complicated:
  - At large distances, the force is dominated by the repulsive electric force (same sign charges).
  - At small distances, the force is dominated by the attractive nuclear force.
- When we compare the total energy of the individual constituents with the total energy of the nucleus, we find that the energy of the nucleus is less => the system is stable against decay.



Calculating the potential energy. The atomic potential energy.

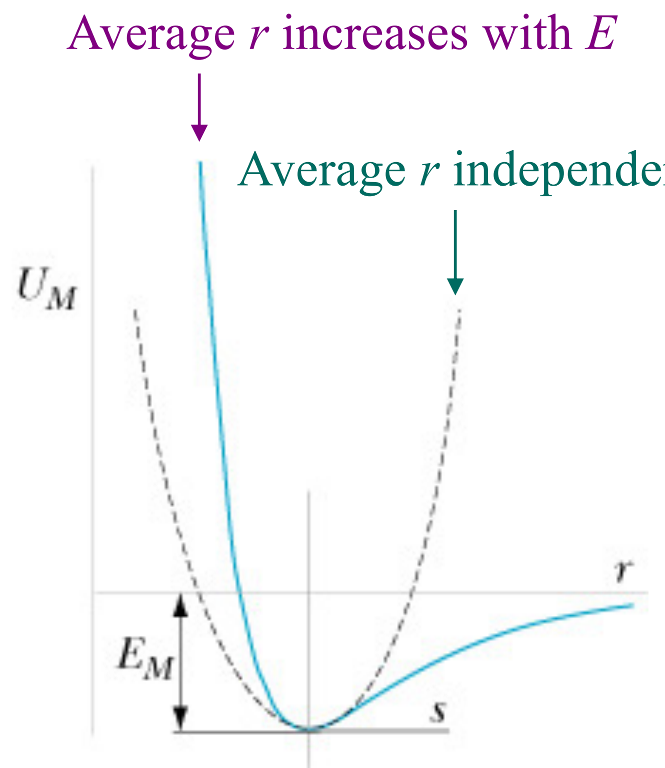
- The force between neutral atoms is largely governed by the electric force between their constituents.
- The net force has contributions due to the repulsive force between the protons and between the electrons in each atom, and the attractive force between the protons in one nucleus and the electrons in the other nucleus (and vice versa).
- The potential energy between two neutral atoms is parameterized in terms of the Morse function.



Note: this will be discussed in more detail in chapter 7.

Calculating the potential energy. The atomic potential energy.

- The Morse potential energy distribution is in approximate agreement with the results of measurements of the inter-atomic force.
- The region surrounding the equilibrium position may be approximated with the potential distribution of a harmonic oscillator (e.g. a spring).
- For small oscillations around the equilibrium position, the spring model will work nicely!



Note: this will be discussed in more detail in chapter 7.

That is all for today.
Next lecture: Chapter 7!