Today we will spend some time strengthening our understanding of the concept of potential energy, and how we come up with models for the potential energy in physical systems, and how we represent these graphically. The reason why we need to do this is because the idea of *force* is not particularly useful for thinking about quantum mechanics — the idea of *energy* is much more natural and makes the equations much simpler. In quantum mechanics we figure out the potential energy for a system and then use that to calculate the behavior. Sometimes we know exactly what the potential energy is as a function of position, but more often we come up with some approximate model of reality that we use in our calculations. Quantum mechanical books are filled with model potential energy curves, and it is important that you understand what these curves are representing and where they came from.

Part 1: The Concept of Energy

When you learned Newtonian mechanics, do you remember why the energy concept is so useful?

Imagine that this question is given to some 1st year physics students in another tutorial today and that you are tasked with helping them answer it. A very good way to help them would be for you to come up with two different physics problems where the *energy method* (E^{total} = KE + PE) you learned in first year physics is a lot easier to use than the *force method* ($\vec{F}^{net} = d\vec{p}/dt$) and solve both problems. The first physics problem you invent should involve a gravitational force, while the second one should involve an electrical force. (No frictional force allowed! Potential energy is associated with conservative forces only.)

Part 2: Gravitational and Electric Potential

In the following problem there are two distinct forces: a gravitational force and an electrostatic force. Given these forces ($\vec{F}^{grav}$ and $\vec{F}^{elec}$), we want you to sketch the corresponding expression for the potential energy $U(\vec{r})$.

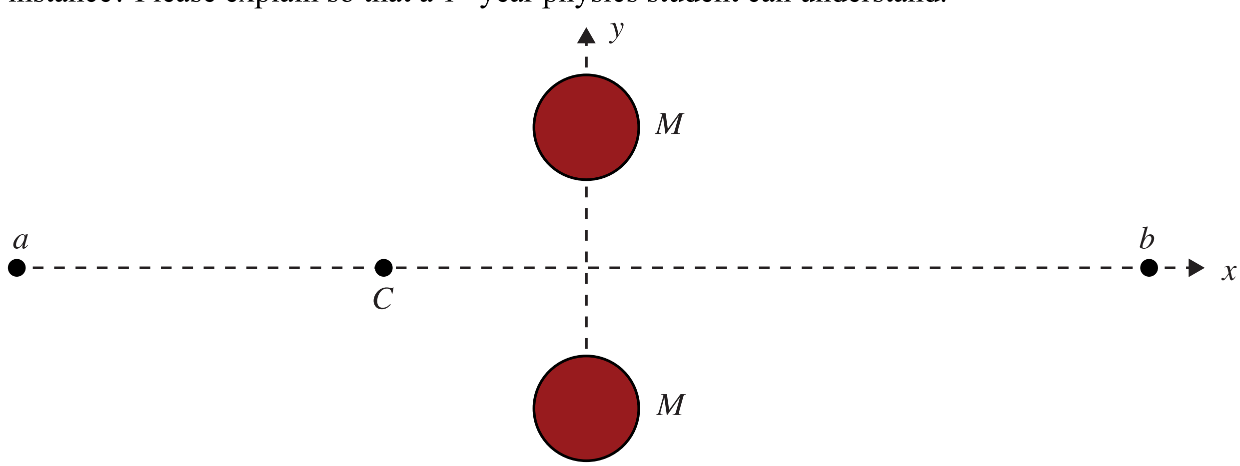
Here's the scenario, as shown at the bottom of this page: A space probe is set to travel between two red giants having the same mass M (red giants are luminous giant stars in the late phase of stellar evolution). To complicate the matter, the probe and both red giants have a net positive electric charge such that the electrostatic force on the probe at point C is 90% the magnitude of the gravitational force on the probe. Considering these two types of forces, mission planners want to know if it's possible to draw a potential energy curve $U(\vec{r})$ for the probe-stars system as the probe travels between points $x = a$ and $x = b$. If a potential energy curve for the probe-stars system exists, we want you to:

(a) Sketch the shape of the potential energy curve on the graph on the next page (Graph 1), first assuming that the probe is NOT electrically charged. (The mission planners are primarily concerned with its shape as opposed to an exact expression).

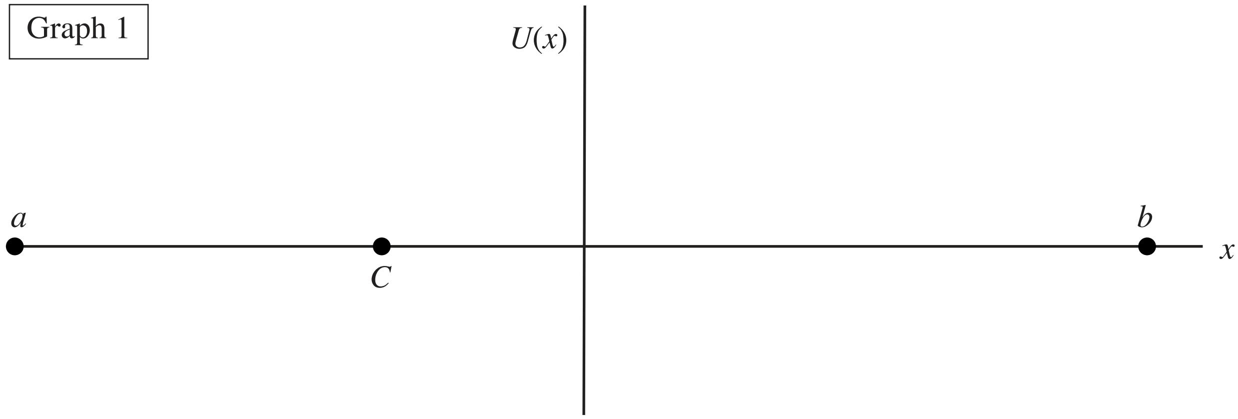
(b) Sketch the shape of the potential energy curve on the graph on the next page (Graph 2) with the probe electrically charged. *Make sure that the vertical scale is the same on Graphs* 1 & 2.

(c) Sketch the shape of the potential energy curve on the graph on the next page (Graph 3) with the charge type on the probe reversed (switched to negative instead of positive).

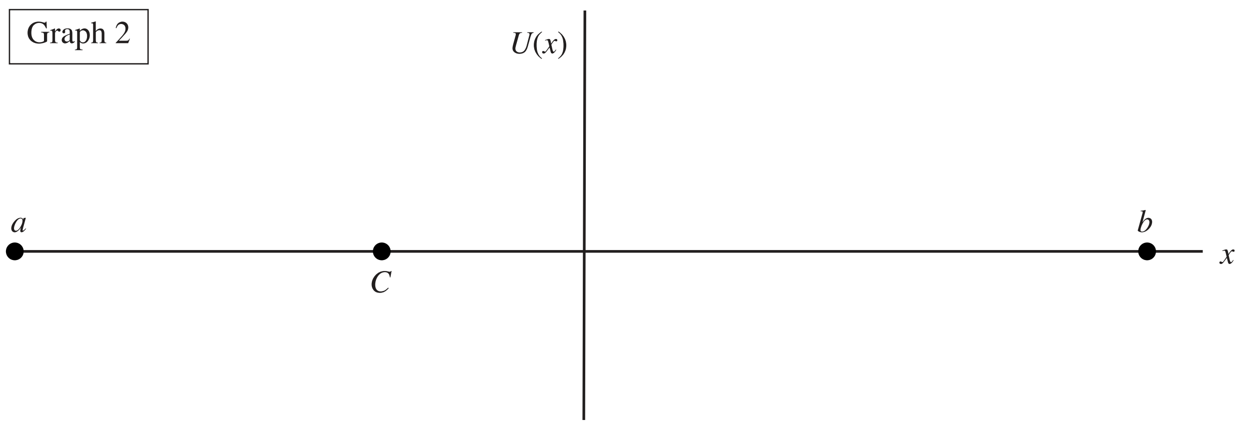
(d) What does the potential energy belong to? Is it the potential energy of the probe, for instance? Please explain so that a 1st year physics student can understand.



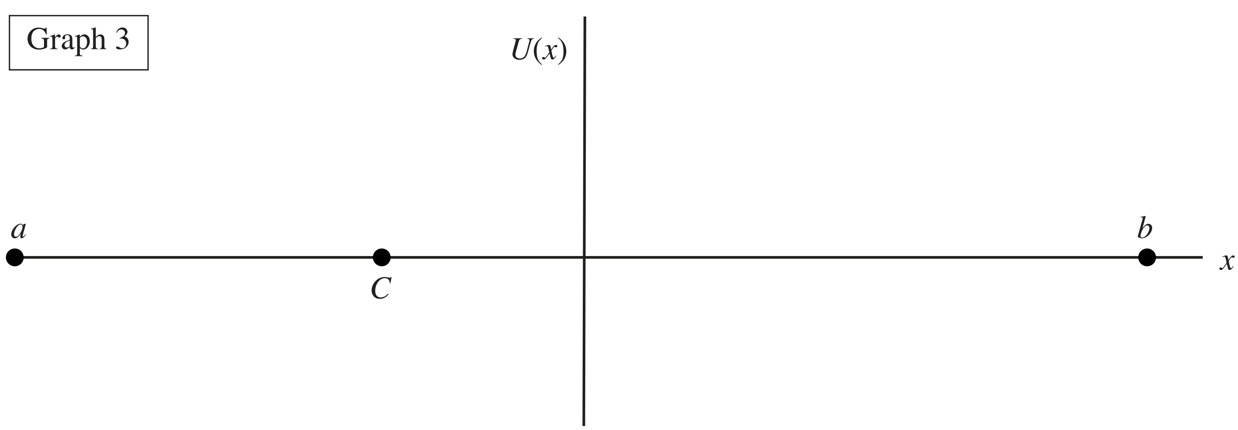
Graph 1



Graph 2



Graph 3



Part 3: Molecular Bond

Now let's look at modeling the potential energy that produces the molecular bond between two atoms in a diatomic molecule like H_2, O_2, HCl, etc. This is a very important and interesting example.

Two atoms combine to form a diatomic molecule because of a net attractive force between them. This binding force is electrostatic in origin and is therefore conservative, so we can use the concept of potential energy to describe this physical system. The detailed analysis needed to compute the force $\vec{F}(\vec{r})$ (or the corresponding potential energy $U(\vec{r})$) as a function of distance $\vec{r}$ between the two atoms is actually very complicated. In fact, until the advent of modern quantum mechanics, all we had were empirical observations of the net interacting between these atoms. Given a few of these experimental observations (listed below), we want you to model and then sketch a potential energy curve $U(\vec{r})$ that describes in approximate way the electrostatic interaction of the two atoms a distance r apart. (*Note*: that is exactly what physicist had to do before quantum mechanics.)

(1) The force between the two atoms goes to zero when the two atoms are separated by an infinite distance.

(2) As the atoms are brought closer together, both attractive AND repulsive electrostatic forces come into play. At large separation (not infinity) the net force is attractive. For larger and larger separations, the net attractive force gets weaker and weaker. On the other hand, at very small separation the net force becomes repulsive as like charges begin to repel each other. In fact, this repulsive force seems to get stronger and stronger as r approaches zero.

(3) At a separation r_0, the attractive and repulsive forces balance each other.

Sketch the potential energy curve $U(\vec{r})$ for the two-atom system on the first graph on the next page. When you are done with your sketch of $U(\vec{r})$, use it to sketch the force $\vec{F}(\vec{r})$ between both atoms.

Hint: What do you think the potential energy of the two-atom system should be when they are both at rest, infinitely far apart ($r \to \infty$)?

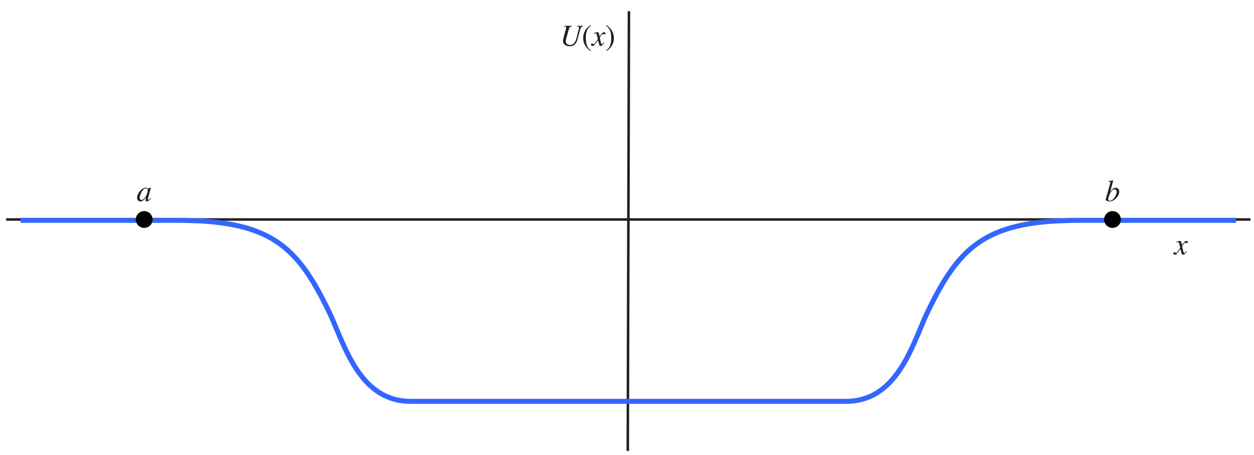

U(r)
r
r0


F(r)
r
r0

Part 4: Insulator Rod

This time we're flipping things around — we're **giving** you the potential energy curve and you are asked to come up with the corresponding charge/mass distribution giving rise to this potential.

An electron is free to move along the *x*-axis (shown below). A thin insulating rod has an unknown charge distribution on its surface. We want you to find the charge distribution. (Write "+" and/or "–" signs on the rod to indicate the presence of positive and/or negative charges).



Dielectric/insulator rod

Tutorial by Dr. Chris Cline at Westminster College.