ACTIVITY 4

A Single Interaction and Other Things

Goal
We look at one more situation in which an object is trapped by an interaction, then complete a summary exercise to apply all that you have learned.

In the previous activity we trapped a car by placing it between two locations where repulsive interactions occur. We can also trap an object with one attractive interaction.

? Begin by setting up a situation so that the car is trapped by an attractive interaction. Describe below how you did it.

? You also used an attractive interaction in Activity 1. How is this situation different?

Remember the potential energy far from the magnets will be zero, and we define attractive potential energies to be negative. Sketch the potential energy diagram for the interaction that you have created. Again, assume that you can ignore friction. Draw only the potential energy due to the magnets.

Now, draw the total energy on this potential energy diagram as if friction were zero. To think about the value of the total energy, consider the turning points. For the object to be trapped, it must have two turning points. Thus, the total energy line must cross the potential energy curve twice. Use these concepts to draw the total energy line.

Based on our previous activities we must conclude that the total energy is negative when a single interaction traps an object. In this situation we have a negative potential energy and a negative total energy; only the kinetic energy is positive.

For many situations such as electrons in atoms, the object is trapped by one interaction. When objects are trapped in this way, we say they are in a *bound state*.

The binding energy for an object in a bound state can be determined as we did in Activity 3. It is the difference between the energy when the particle is *not* trapped and the energy when it is in the bound state.

In Figure 4-1 are energy diagrams which show the potential and total energies for an object. What is the binding energy for each object?

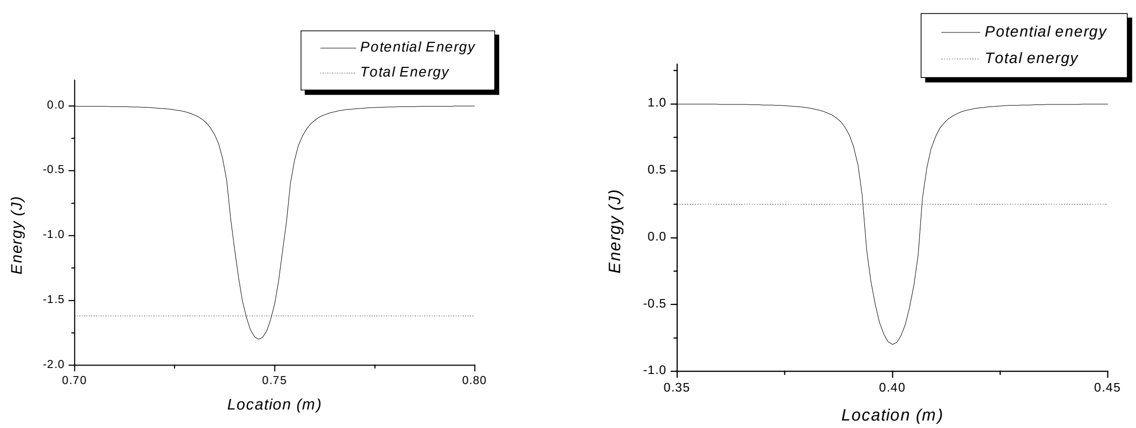

Figure 4-1: Energy diagrams for two situations.

This type of energy diagram is most useful when studying atoms. It will help us understand how energy changes in atoms and how light is created by atoms.

Catching a thief using potential energy diagrams

One of the advantages of the potential energy diagrams is that they provide many details of motion - one does not need to be present when a motion takes place in order to describe it. To provide you with a better understanding of the value of the potential energy diagrams and to prepare you for the study of atoms and nuclei, imagine the following situation:

As a secret agent you need to use your physics background to stop the theft of stolen paintings. The shipment of stolen art works is being moved by truck. Your partner has attached a large magnet underneath the truck. She needs to communicate to you where to place magnets along the road so the truck can be trapped and does not leave the country. However, she fears that any note could be intercepted. She knows that thieves usually sleep through physics class, so she draws a potential energy diagram and sends it to you. You receive the following drawing:

The horizontal dotted line on the diagram represents the total energy of the truck.

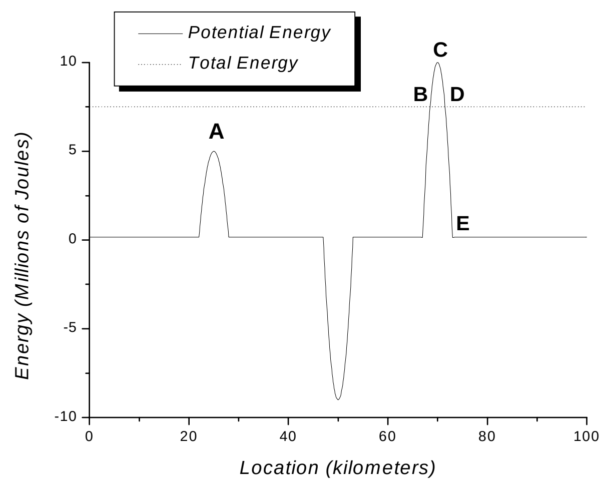

Figure 4-2: The energy diagram for the "catch a thief" scenario. The changes in potential energy shown here are larger and broader than are possible with real magnets. They were drawn this way so that they would be easy to see. After all, it's all fiction.

(This way of catching thieves may seem rather strange, but James Bond does even stranger things.)

? Which are the points reached by the truck when it moves from left to right with total energy as indicated on the diagram?

? Describe the motion of the truck at these points in terms of speed changes. The truck is moving from left to right.

? Describe the motion of the truck if it has twice as much total energy as indicated on the diagram and still moves from left to right.

? In terms of locations reached by the truck, what was different in the two situations?

? Explain how you used the potential energy diagram for your descriptions.

The final and most important step of your job is interpreting the drawing and helping to capture the thieves. The data that you need are available on your diagram. The truck is always on a flat road.

? Indicate where you would put magnets to create the potential energy diagram. Also state whether they would attract or repel the truck.

? List the points along the road (in km) which will result in a turning point for the truck.

? To accomplish your mission of trapping the truck, your colleague tells you to reverse a set of magnets just after the truck passes. Which set would result in trapping the truck? Explain your answer.

In this activity you have learned how the potential energy diagram can be used to predict and describe the motion of an object. The behavior of any object at a particular location in space can be determined by the potential energy diagram that represents the object's motion and object's total energy. In your assignment as a secret agent you applied your knowledge to macroscopic objects (the truck). When you study very small objects such as atoms and molecules, you will use energy diagrams and identical reasoning patterns. However, for one aspect — turning points — you will see that we must modify our ideas about what is possible.

Unit Summary

In these activities we have presented energy as a method of describing motion. To use this method you need to create a potential energy diagram from the physical situation, then use it and knowledge of the total energy to determine other variables of the motion such as speed and acceleration. Conservation of energy is crucial to understanding the energy diagrams. A decrease in potential energy means an increase in kinetic energy and vice versa. Thus, by looking at a potential energy diagram with the total energy marked on it, one can quickly use conservation of energy to describe the motion.

Inspection of energy diagrams quickly tells where an object such as a toy car can be. If a region exists where the potential energy is greater than the total energy, the object cannot enter that region.

Because the object cannot be in a region, it must turn around. The *turning point* is the location at which the object turns. At this point the potential energy is equal to the total energy.

If two turning points exist, the object is trapped in the region between them. By looking at an energy diagram you can easily determine the region in which the object is trapped.

When an object is trapped, it can become free of its trap only if it receives additional energy. We can determine this energy by calculating the difference between the total energy and the maximum value of the potential energy. This difference is the *binding energy*. When an object receives its binding energy, it is no longer trapped.

An object can be trapped or *bound* by an interaction with one other object. In this case the interaction must be attractive. We define the potential energy to be negative for these attractions. If the total energy is also negative, the result will be a *bound state*. Electrons in atoms are in bound states.

The energy diagram method enables us to determine quickly several features of an object's motion. It will be very helpful when we study electrons — and we will find that electrons do not behave quite the same way as toy cars.