ACTIVITY 3

In a Trap

Goal

You will look at the motion of a car constrained to move in a small region of space and use diagrams to determine

- the range of energies for which the car will be trapped, and
- the energy needed to "break the car free" from its trap.

When you study properties of materials, you will find that many objects have their motion restricted to a small region of space. For example, electrons stay close to their atoms, and atoms in a solid are restricted in their motion by their interaction with other atoms. We say that these objects are *trapped* by their interactions with neighboring objects. When you study trapped electrons and atoms, you will use potential energy diagrams. To become prepared you will now consider with potential energy diagrams representing a car that is trapped by interactions with magnets.

You are already familiar with the attractive and repulsive situations, in which the car managed to escape the magnets and went all the way to the end of the track. In this activity, you will use conservation of energy and the total energy of the car to focus on another question: what conditions allow a car to be trapped in a region of space? You will start with a car initially repelled by one pair of magnets and later trapped between two pairs of magnets. Keep in mind that in your experiments you use the magnets as a convenient way of creating change in potential energy. However, these diagrams can be created with other objects as well.

For example, the interactions between electrons and nuclei are of non-magnetic origin. In this unit, you will be concerned only with the shape of the diagrams, not with the origin of interactions.

Car repelled by a pair of magnets

? Based on what you have learned from Activities 1 and 2, how would you arrange the magnets (as attractive or as repulsive) to create the following potential energy diagram?

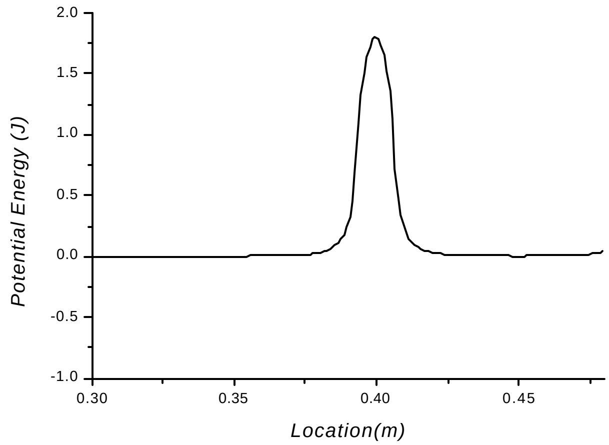

Figure 3-1: A potential energy diagram.

In general, when we work on a certain task, we always prefer to have as much information (data) available as possible. In the example with the car, to completely analyze its behavior, you will need an additional piece of information --- the total energy of the car. The total energy (*potential* + *kinetic*) is often represented by a horizontal line added either to the kinetic or potential energy diagrams. From now on we will draw the total energy as a line relative to the potential energy diagram, as shown in Figure 3-2.

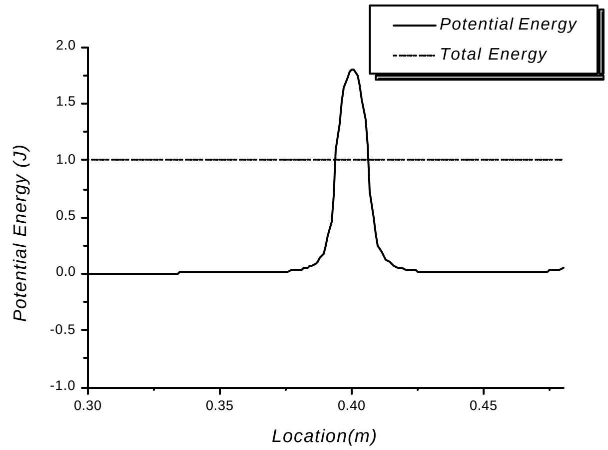

Figure 3-2: A potential and total energy diagram.

? Why should we draw the total energy as a flat line, while the potential energy changes in situations where we ignore friction?

Consider a car which has the total energy indicated in Figure 3-2. It is approaching a set of magnets from the right that have the potential energy represented by the solid curve. See Figure 3-3.

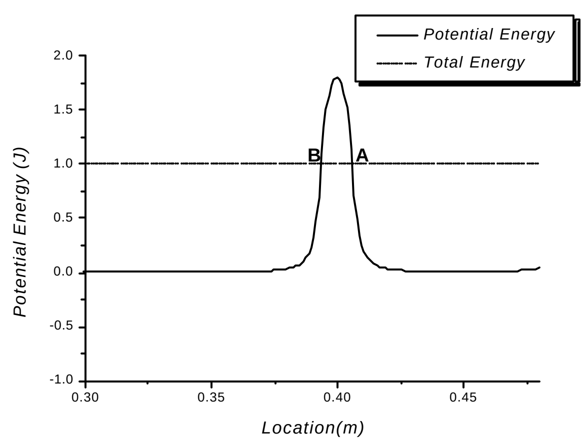

Figure 3-3: The magnets repel and the total energy is less than the maximum potential energy.

? What is the value of the kinetic energy:

a) at .44 m;

b) at point A, where the potential energy and total energy are equal;

c) at .40 m;

Notice that in the region between points A and B the kinetic energy *that we calculate* is negative. This result is a difficulty. The mass of the car is always positive and so is the square of its velocity. Thus, kinetic energy can not be negative. A negative kinetic energy has no physical meaning! For a negative kinetic energy to exist, it has to be associated with negative mass or negative $(\text{velocity})^2$. Neither of these is physically possible. The car cannot have a negative kinetic energy, so it does not go into regions where we would calculate a negative kinetic energy.

Therefore, it is not physically possible for the car to get to the *left* of point A. When the car approaches point A from the right, it will stop at point A and turn back in the opposite direction.

Arrange the magnets so that you have a situation represented by the potential energy diagram in Figure 3-3.

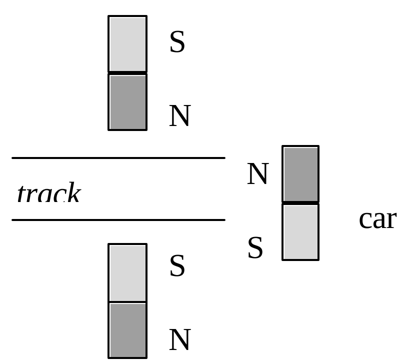

Figure 3-4: A situation in which the car is repelled by a pair of magnets.

Push the car, so that it turns around near the magnets. Then, sketch the approximate values of the total energy and the potential energy on the diagram in Figure 3-5. Mark the location at which the car turns around as point.

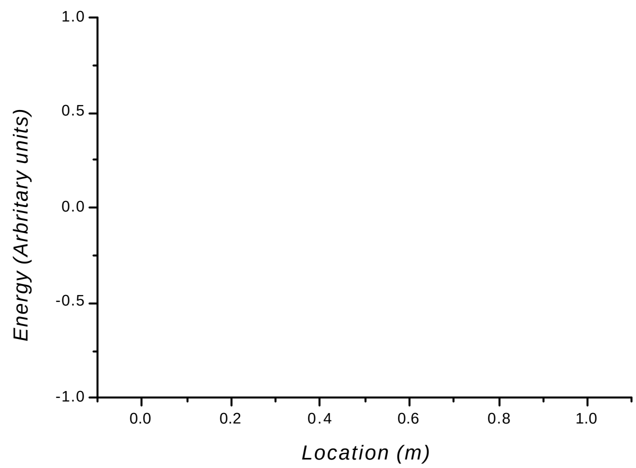

Figure 3-5: A potential energy diagram.

Now give the car a stronger push. What does the car do when it approaches point A (i.e. near the magnet)? Sketch in Figure 3-6 both the total energy level of this car and its potential energy. Indicate on this graph the approximate location of point C from the previous graph in Figure 3-5.

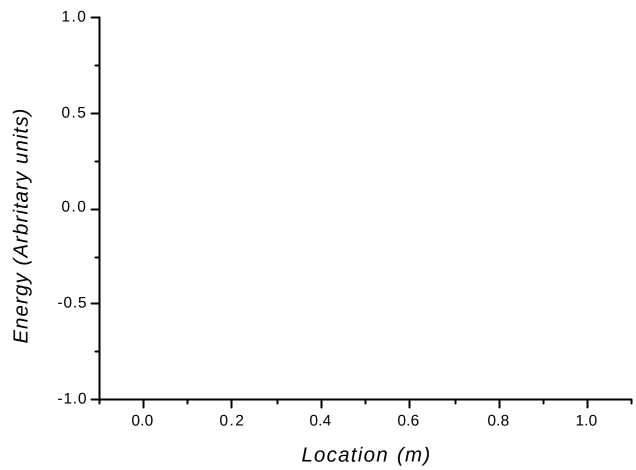

Figure 3-6: An energy diagram for a stronger push than in Figure 3-5.

Warning! The car is approaching a trap!

When we study atoms, we will look at several situations where two objects attract each other and, thus, stay close together. For example, an electron and a proton become a hydrogen atom because of their attraction. One way to learn about atoms is to consider the potential energy created by the attraction, then analyze the electron's total energy. To become prepared for that analysis we will now look at cars trapped by magnets.

We wish to establish a situation where the car is moving but it is trapped in a certain region of space. Arrange magnets (as many as you need) to create a situation where the car can be trapped in a region of space. Describe your arrangement of magnets.

? Draw the potential energy diagram for this situation.

? Use the potential energy diagram to explain why your arrangement will result in a trapped car.

? Now give the car a push that allows it to escape from the trap that you have created. Use energy to explain why the car can escape.

? Sketch your potential energy diagram again below. Then draw and label a possible total energy of the car when:

1. it is trapped in one region of space and
2. it escapes from the region.

? The potential energy diagram in Figure 3-7 shows one possibility for getting trapped car. On this diagram draw the maximum total energy level which the car can have and still remain trapped by two pairs of magnets. Explain your answer.

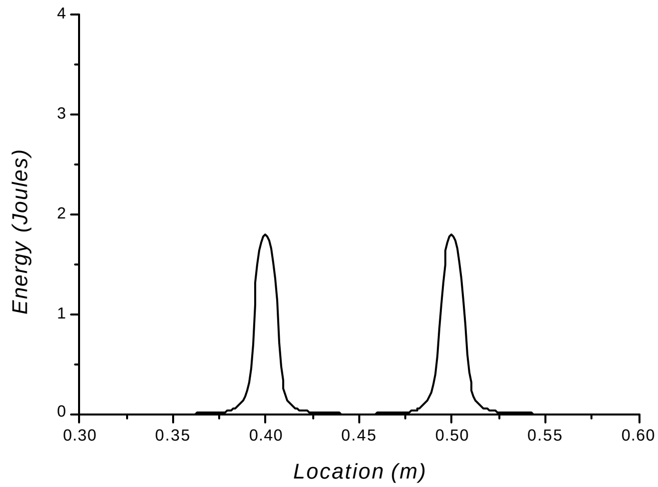

Figure 3-7: A potential energy diagram for a trapped car.

Notice that for some locations on the diagram the total energy of the car equals its potential energy. On one side the potential energy is greater than the total energy. This situation is equivalent to the kinetic energy having a negative value. Thus, the car will stay in the region where potential energy is equal to or less than the total energy. At the locations where the potential energy and total energy are equal, the car comes to a momentary stop, then changes direction. The locations where the car momentarily stops are called *turning points*.

The diagram in Figure 3-8 shows potential and total energies for a car. Indicate on the graph the car's turning points.

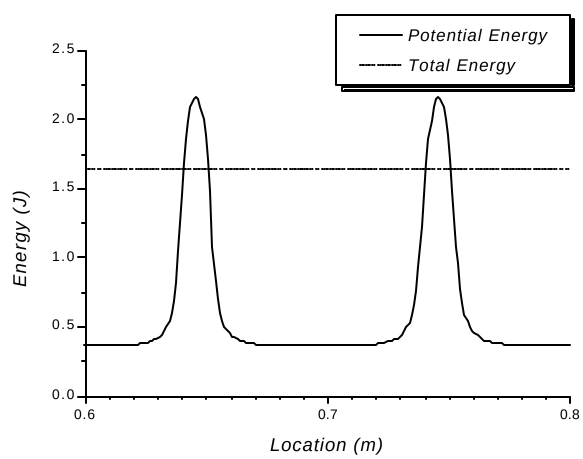

Figure 3-8: For this situation determine the turning points for a car that starts moving at 0.7 meters.

Identifying the turning points is a useful way of describing the region in which an object is restricted. Using potential and kinetic energy is an easy way to determine the turning points.

Once trapped, will the car stay there forever?

When an object is trapped in situations similar to the one represented by Figure 3-8, it must receive some energy if it is to get out of the trap. Suppose you wanted to help get this car out of its trap.

? How much energy would you need to give the car represented by Figure 3-8 so that it would no longer be trapped?

The energy needed to remove an object from a region in which it is trapped is called the *binding energy*. The binding energy is the *difference* between the maximum potential energy and the object's total energy.

Application — If friction were not present

Once again friction causes difficulty in seeing what happens when no energy leaves the car. To have a friction-free experience use the *Potential Energy Diagram Sketcher* program. Set up a situation that creates the potential energy diagram in Figure 3-7. Give the car the approximate total energy shown in Figure 3-8.

? Describe the car's motion with

- Large friction

- Small friction

- No friction

? Now, calculate the binding energy. Then, give the car that much energy. What happens?

Each member of the group should set the total energy of the car to a different value. Other group members should calculate the binding energy. Then, see if that amount of energy frees the car from its trap.

The attractive and repulsive diagrams that you have created were diagrams of simple shapes - representing an object being first accelerated and later decelerated (or vice versa). However, the motion of an object is often more complex. The next activity is an introduction to potential energy diagrams of complicated shapes and their application.