A Model Potential Well

Introduction

The concept of a potential well is an important one in physics. It is used, among other things, in the understanding and analysis of the forces and energy involved in gravitation and electric charges. This article describes how to make and use a simple model of a potential well.

Key Physics Areas

- Fields
- Gravity
- Potential energy
- Orbits of planets and satellites
- Keplers Laws

Connections to the NSW Physics Syllabus (Stage 6)

"Space" HSC topic

Materials Required

- 1 Latex rubber swimming cap.
- 1 Large plastic flower pot, approximately 30 cm diameter
- 1 Wooden baseboard (e.g. a piece of chipboard or MDF 30 cm square)
- 1 Screw eye (eyelet)
- 1 small screw (e.g. a self tapping screw)
- 2 small circular pieces of rubber, approximately 1 cm diameter. These can be cut from a rubber sheet, such an old tyre.
- Strong string (e.g. nylon sail string, or fishing line.)
- Rubber glue (e.g. Contact Cement)

Construction

Cut the bottom from the flower pot, using a sharp knife (e.g. a Stanley or hobby knife).

Glue the two rubber circles opposite each other on the top and the bottom of the cap, clamping them to the cap if necessary. If using contact cement, allow the glue to set overnight. (Five-minute epoxy has been successfully used for this purpose.)

Stretch the swimming cap across the top of the flower pot and over the rim. Centre the rubber circles. (Alternatively, it may be easier to stretch the cap over the flower pot first, and then glue the rubber circles on.) Make sure that the rim of the plastic pot is smooth; otherwise, the swimming cap may tear.

Using a needle with a large eye (a tapestry needle is good for this), thread the string through the rubber circles, and tie it off at the top. Make sure that the string cannot be pulled all the way through the top rubber circle. This can be prevented by tying the string to a small button. The purpose of the rubber rings is to allow the string to be threaded through the swimming cap without ripping it.

Screw the eyelet into the centre of the baseboard. Fasten the small screw near one edge of the baseboard. This will serve to anchor the string.

Position the flowerpot over the centre of the baseboard, and thread the string through the eyelet. Pull the string through one of the drainage holes at the base of the pot, and anchor it by wrapping several times around the small screw. A little bit of sticky tape will prevent the string from unraveling off the screw.

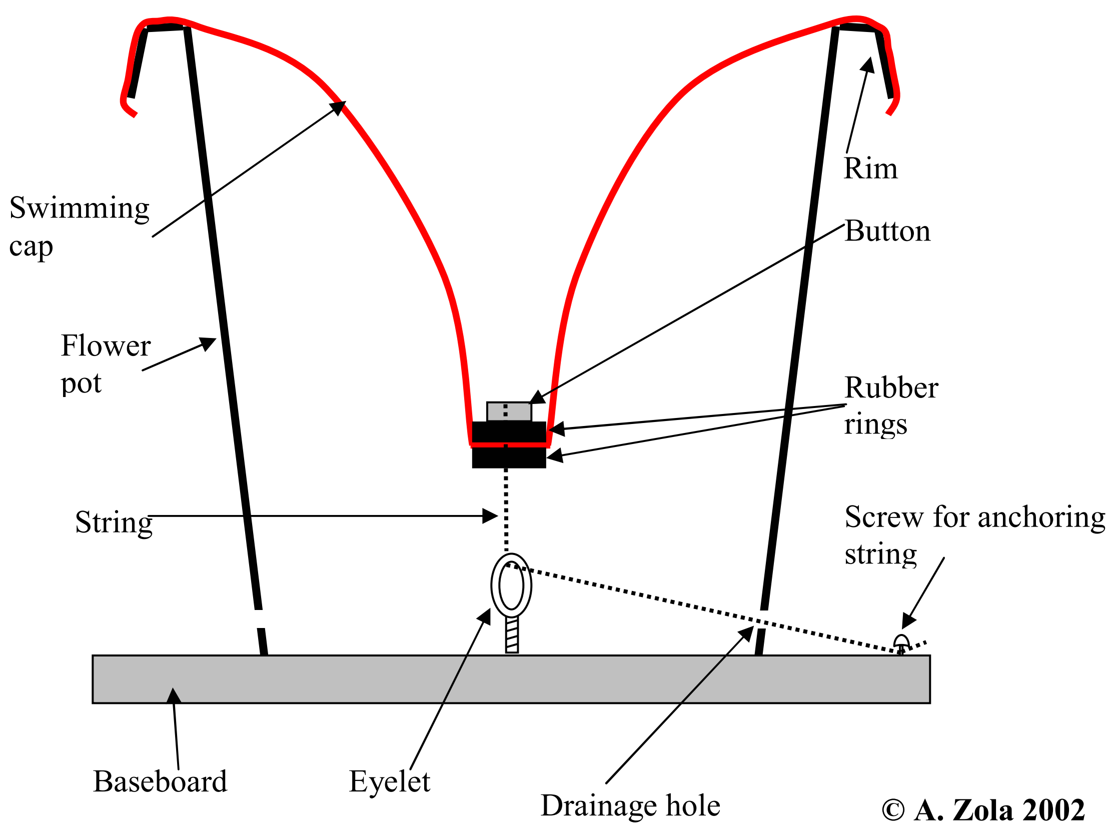

Figure 1: Details of construction

Figure 2: The model in action, viewed from above.

Applications and Sample Experiments

A number of investigations and demonstrations are possible using the model described above.

Orbits of Satellites

The orbit of satellites around their parent body can be simulated by rolling various objects around the rubber sheet. Marbles or ball bearings may be used, but coins work especially well. If several coins are used (to simulate planets orbiting the Sun) they will roll very close to each other, usually without colliding. This is fascinating to watch. The radius of the orbits eventually decreases (due to energy losses) and the increase in orbital speed as this happens is very obvious. This can be used to demonstrate (very effectively) that the closer a satellite moves to the parent body, the faster it moves to maintain a stable orbit.

Figure 3: Several coins can be used to simulate a solar system.

The coins initially move around the centre of the funnel in an ellipse, but usually settle quickly into a circular path ('low Earth orbits').

Kepler's Laws

Another experiment may be performed to verify Kepler's Third Law. A series of concentric circles of known radii are drawn on the stretched sheet. A coin is rolled and its period of orbit is measured with a stopwatch when its path coincides with each of the circles. (Having several people measuring this period leads to more accurate results.) In this way, data about the period of revolution (T) at different radii (r) are gathered. A plot is then drawn of the cube of the radius vs. the square of the period. The resulting graph yields a straight line, confirming the linear relationship between r^3 and T^2.

Gravity Field around Objects

If you look carefully at the coin as it rolls around, you can see that it makes its own depression ("gravity") in the rubber sheet. The interaction of two gravitational fields can be simulated in this way.

Dependence of Gravity on Mass

The depth of the funnel can be varied by pulling the string and anchoring it. This allows the potential well of different masses to be compared. Even a black hole can be simulated if the cap is pulled down as far as possible (!) to give the deepest possible well.

Measuring Orbital Speed

Although I have not yet tested the following ideas, they allow some scope for experimentation.

As a coin rolls around the well, a distinct sound will be heard. Corrugations on the edge of the coin (called reedings) strike the rubber surface as it rolls around. The rubber surface vibrates, producing the sound. The frequency of the sound will depend on the number of reedings around the circumference, and the speed of the coin. For an Australian 20 cent coin, there are between 219 and 225 reedings around the circumference. If this frequency is measured (e.g. with a data logger, or a frequency meter) then the angular velocity of the coin (ω) can be measured. Knowing the radius of the coin (r) then allows the orbital velocity (v) to be calculated, using $v = r\omega$.

Surprisingly, even an Australian 50 cent coin, with its dodecagonal outline, will roll around the well. Using this coin for this particular experiment will make verifying results a good deal easier. Sound will be produced when each of the corners strikes the rubber sheet as the coin rolls around. If concentric circles are marked on the rubber sheet, as described above, it should be possible to collect data about orbital velocity at different radii, and hence to verify the relationship between them, i.e. $v^2 = const \times 1/r$.

Electric Field around (Negatively) Charged Objects

If radial lines are drawn from the edge of the model towards the centre, a negative charge may be modeled. A small positive test charge (ball bearing) will move toward the 'negative' charge when it is released. Alternatively, this small 'test charge' may be used to deduce the shape of the field surrounding the 'negative charge' by tracing the path that the ball bearing follows when it is released in the field.

Alternative Methods and Materials

There are many different ways in which a model potential well can be constructed. The version described above has the advantages of being very simple, and can be constructed in a minimum of time with very commonly available materials. There are many other possibilities, and a few of these are described below.

Using trampolines

A heavy weight (e.g. a person) is placed on a trampoline. This creates a depression (potential well) around the heavy weight. If a shot-put ball or a bowling ball is rolled past it will be deflected (or even trapped into orbiting) by the 'gravitational pull' of the heavy weight. The effects are not as spectacular as in the model constructed above, and the balls usually only make a few orbits before falling into the well and ceasing the motion. Large trampolines tend to be fairly taut, so the depression made is generally small, and the motion dies out quickly due to friction. It is useful, however, for demonstrating motions where the ball is not captured into orbit. Elliptical orbits seem to be much easier to produce with a trampoline than they are with the other models described, and the motion is slower and easier to appreciate. It also has the advantages of being large, and students are involved as part of the model if they are used as the central mass.

Figure 4: A golf ball orbits about a gravitational potential well created by a person standing on a trampoline.

Figure 5: A mini-tramp is used as a gravitational potential well. A broom handle pushed down in the centre creates the necessary depression. A golf ball serves as the body in orbit.

In another version, a ‘mini-tramp’ is used. The centre of this trampoline is held down with the top of a broom handle in order to create the depression. (A frame could be made up to hold the broom handle in place, and possibly to give some kind of adjustment for the depth of the depression.) Golf balls seem to work really well with this type of setup.

Using other materials

Ideally, a large rubber sheet could be stretched over a support so several objects can be placed on it. In this way, the gravitational field around each object can be simulated. If the objects are sufficiently close to each other, they may experience mutual attraction as they each move into the potential well of the other.

If different masses are placed on the rubber sheet, they will create wells of different ‘depths’. In this way, the stronger gravitational field around a more massive object can be visually demonstrated.

Such a sheet of rubber has proven difficult to locate, so an easier alternative is to use a stretchy fabric known as spandex or lycra. If a large enough frame is constructed to hold it, a piece of gardening shade-cloth may also be used.

Using Rubber Balloons

Excellent results have been obtained by stretching a rubber balloon over the flower pot instead of the swimming cap. Coins orbit for much longer periods of time, and the other experiments also generally work better. However, it is more difficult to build this version of the potential well, and it generally only lasts a few days before the rubber tears.

The main problem is in stretching the balloon itself, then keeping it in place. In order to do this, glue is smeared on the inside rim of the flower pot. A large balloon is inflated, tied off then wedged inside the flower pot so its edge is in contact with the glue. Another bead of glue is then smeared between the balloon and the rim, and allowed to set. This may take some time, depending on the glue used. Once the glue has set, the joint between the balloon and the rim can be reinforced by using a layer or two of plastic electrical tape over the joint.

The balloon is then popped by making a small hole near the top where it has been tied off. The rubber is less stretched at this point, and the air should escape slowly. With any luck, the bead of glue will hold the bottom of the balloon taut across the pot. The remaining part of the balloon may be trimmed, and then folded back over the rim of the pot. More electrical tape can then be used to hold this in place more securely.

Reinforcing circles of rubber can then be glued to the stretched balloon, as they are in the swimming cap version described above. String can then be threaded through the balloon without it popping.

The choice of glue is a matter of experiment. I have used a construction adhesive called Liquid Nails successfully, but there may be others that are better suited for the purpose. Some types of glue will degrade the rubber quickly, and others do not stick to the rubber or the plastic pot.

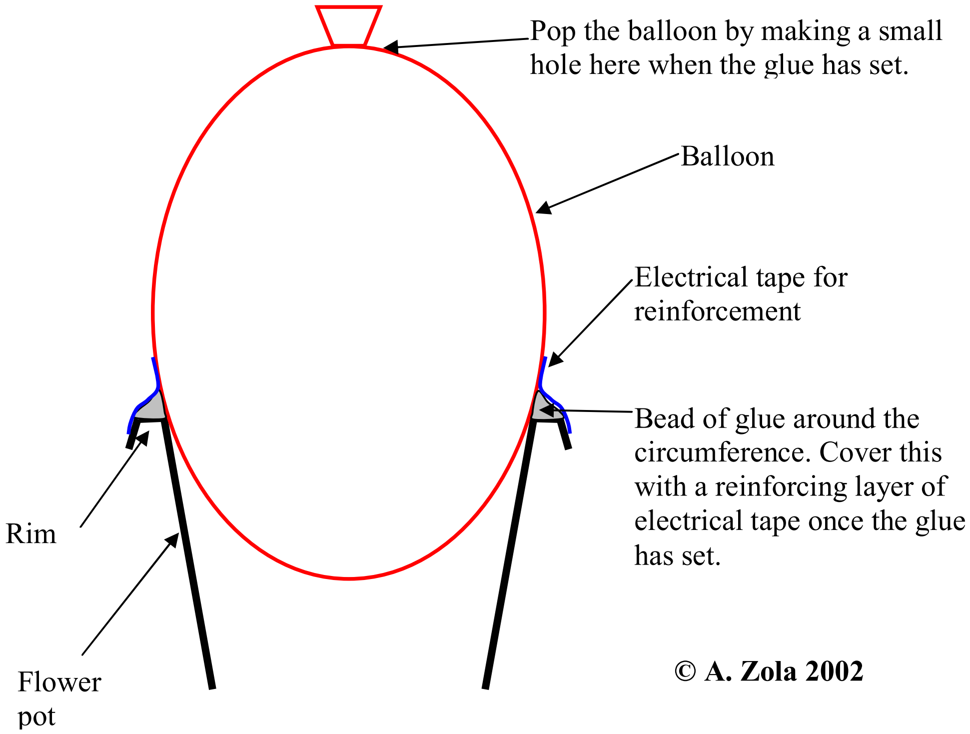

Figure 6: Using a rubber balloon to make a potential well. In this step, the balloon is glued to the pot.

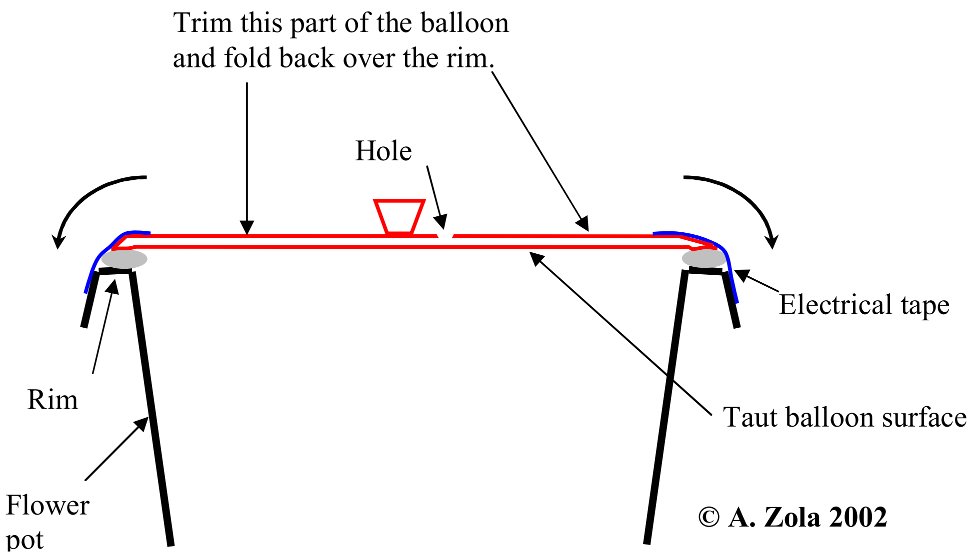

Figure 7: The balloon is popped.

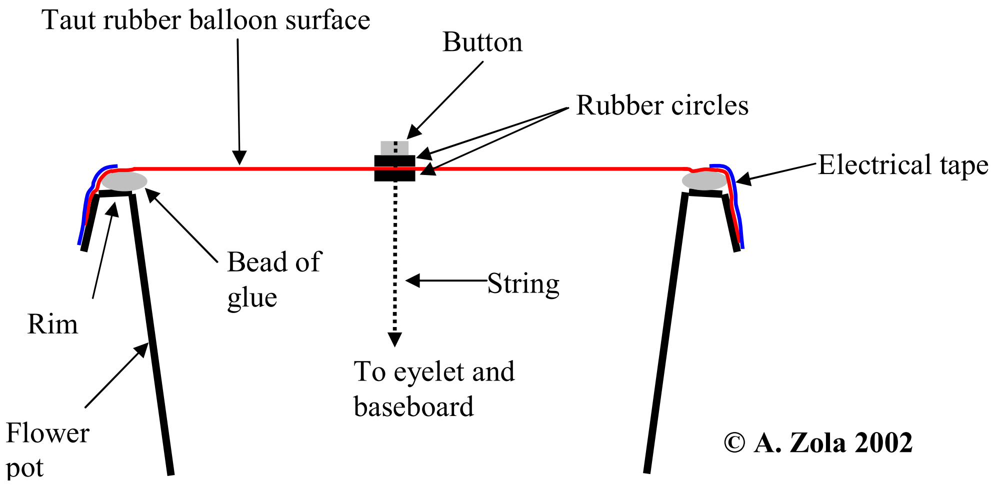

Figure 8: The balloon is folded back over the rim, and reinforced.

More balloons

In another experiment, a coin is placed inside a balloon and the balloon is then inflated and tied off. The balloon is then rotated quickly in order to get the coin inside to orbit around. The disadvantages of this experiment are that the coin is inside the balloon and the shape of the curve of the inside wall of the balloon is the 'wrong way around'. However, it is a quick and simple experiment to do, and the coin orbits for a surprisingly long time.