Artesian Well

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Abstract:

The Artesian Well Module is an inquiry-based, interdisciplinary activity. A model of an artesian well is used to teach conservation of energy. One may wish to emphasize the geological structure itself—the rock and soil features which create an artesian well, or one may wish to emphasize the physics inherent in it—energy is conserved when potential energy is converted into kinetic energy. It may also be used as part of a larger module on soils and the groundwater system. However, this activity was primarily designed as an exercise in creativity, critical thinking, and scientific methodology. Students make predictions, design their own experiments to test those predictions, and finally share their results and conclusions with the class. It is multipart and may take up to four days to complete, depending on the length of the class period. The segments (see Procedures) are based on a 45-minute class period.

Grade Level(s): 6th – 8th

Objectives:

- Understand that groundwater is part of the water cycle
- Learn about soil conditions that produce an aquifer
- Model an artesian well
- Observe and understand conservation of energy via hands-on experiment
- Practice inquiry-based scientific methodology
- Generate curiosity, encourage creativity, and reinforce critical thinking skills

National Standards:

Standard A: Science as Inquiry: Abilities necessary to do scientific inquiry
Standard B: Physical Science: Transfer of energy
Standard D: Earth and Space Science: Structure of the earth system

New Mexico Standards:

Strand 1, Standard 1: Scientific Thinking and Practice; Use scientific method
Strand 1, Standard 1: Scientific Thinking and Practice; Understand process of scientific investigation
Strand 2, Standard 1: Physical Science; Forms and properties of matter
Strand 2, Standard 3: Earth and Space Science; Behavior of solar system and universe
Strand 2, Standard 3: Earth and Space Science; Earth and atmosphere structure

Materials:

- Poster paper
- 2-mm hole punch
- 1-pint funnels
- Meter sticks
- Scissors
- Clear, vinyl tubing
- Rubber bands
- 200-ml beakers
- Plastic paint trays
- Water
- Colored pencils

All materials can readily be found at any home center. Clear vinyl tubing costs about 25¢ per foot. An outer diameter of ¾ inch (5/8 inch inner diameter) works best with standard 1-pint funnels. The 2-mm hole punch can be found next to drip irrigation supplies, for about $1 each. Plastic paint trays are only needed if students do not have a sink at their lab tables. They will contain the spilt water, but are a bit awkward to use.

Background:

Most middle school students have already seen the water cycle. Perhaps they have modeled it in a closed bottle. They usually have a thorough understanding of precipitation, collection (above ground), and condensation, though they may not be as familiar with transpiration. But many students do not think of groundwater as part of the water cycle. In contrast, most students do realize the importance of groundwater. They were aware of some of the ways that it can be contaminated by above ground pollutants. And they were aware that we, if not careful, might deplete our supplies faster than nature could replenish them.

A brief review of erosion and weathering is recommended to remind students how rock is transformed over time into the soil components we are most familiar with: gravel, sand, silt, and clay. (If they haven't already made an edible soil profile, this is a fun and easy activity easily found online.) Soil porosity and permeability are not activity covered in this module, but the concepts are simple enough for most students to understand without a hands-on lab.

The module begins directly with the artesian well itself. Handout #1 illustrates an artesian aquifer and gives students the vocabulary words associated with an artesian well. A separate glossary provides additional, related terms.

The "pretest," Handout #2, shows how we can model an artesian well with tubing. The tubing represents a confined aquifer—a permeable rock layer surrounded by impermeable layers. Because the water in the funnel is at a higher elevation than the water at the base, its weight (mass times gravity) will cause the water in the tubing to be pressurized. (The end of the tubing is clamped shut.) By making a small hole at the base of the tubing, we create all of the conditions needed for an artesian well.

The difference in elevation of the water between the funnel and the hole imparts gravitational potential energy to the water. Gravitational potential energy (or simple PE) is defined as PE = mgh, where m = mass, g = gravity (9.8 m/s^2), and h = vertical height. All objects in earth's gravitational field have PE, which is a function only of the object's height (because mass and gravity are constant values). In our artesian well model, "h" is the height of the funnel since we can choose the hole level to be "ground zero," where h = zero.

Kinetic energy is defined as KE = $\frac{1}{2}$ mv^2, where m is mass, and v = velocity. By definition, objects with kinetic energy must be moving. In our model, the water in the funnel begins at rest (hole closed) so it has zero kinetic energy. Its energy is 100% PE. As the water falls (hole is opened), its height, "h," is reduced, so therefore so is its PE. Where does the energy go? Conservation of energy requires that an object's total energy is a constant value: $(PE + KE)_{initial} = (PE + KE)_{final}$. When the water reaches "ground zero" where PE = 0, its energy is now 100% KE. The energy has been transformed. (We assume frictionless tubes, a common simplification in introductory physics.)

As the water escapes from the hole, the conditions are now reversed—KE is transformed back into PE as the water gains height. Theoretically, the fountain height will equal the height of the funnel due to conservation of energy. Realistically, the fountain height will be a little lower because some of the water's energy was lost to friction. Also, human error is bound to negatively affect results.

It is assumed that 6-8th graders have not yet had any formal experience with the physical concepts presented here. Therefore most students will incorrectly predict that tube shape and length are determining factors in fountain height. It is important that students are **not** given the correct answers. Nor are they to be graded on their responses. Hopefully their curiosity will be aroused to the point that they *want* to test out these scenarios and discover the answers for themselves.

The next two parts of the module—experimental design and hands-on experimentation—are outlined on Handouts #3 and #4.

In Handout #3, students are asked to design an experiment that will determine which factors contribute to fountain height. They must think critically—what is necessary for a proper experiment? Will they understand that only one variable should be tested at a time? Some students may want to copy one of the scenarios presented in the pretest. While this is not altogether bad, originality should be encouraged. However, it will be necessary to place some restrictions on their creativity due to costs and availability of supplies, time constraints, etc. Also, if tubes are made very long (over 100 cm), the affects of friction will become a factor.

In this section, importance should be placed on scientific methodology. Their design posters should clearly state what they are testing (their *variable*), which factors are to remain constant (their *controls),* and what they predict will happen (their hypothesis). They should include a chart or table to tabulate their data, and space for a written summary and conclusion. Students should explain their setups to the teacher and make any needed adjustments. The teacher should also make note of how much tubing will be needed. If students are in the lower grades, it might be necessary for the teacher to prepare the tubing ahead of time—cut tubes to length, clamp ends, and pre-punch holes. If so, Handout #4, the experiment portion, should be adjusted accordingly.

Handout #4 covers the experiment itself. This will probably take up a whole class period. Discussion of results can be held on the following day. This can be done as a formal presentation or as a casual class discussion. If the experiments went well, the data should support the underlying physics—that tube height is the only factor that determines fountain height.* Most likely their results will not be what they expected. Here Handout #5, which explains conservation of energy, can be given out and covered as a class. Handout #5 also asks them to recall and reconsider their earlier answers on the pretest. Hopefully, the correct answers will now be clear—if they are, you should consider the module a success!

* More than likely there will be some discrepancy in the data, even between groups that performed identical experiments. It will be necessary later to discuss the fact that error is inherent in all experiments, and students should consider the most likely causes of error.

References:

GeoMan's Glossary of Earth Science Terms:
http://jersey.uoregon.edu/~mstrick/geology/geo_glossary_page.html

The Physics Classroom:
http://www.glenbrook.k12.il.us/gbssci/phys/Class/BBoard.html
(click on "Work, Energy, & Power" for information on potential and kinetic energies)

Procedures:

Day 1
Students cover *Handout 1: Artesian Well*. Once students are clear about the basic features of an artesian well, they take the pretest, *Handout 2: Artesian Well Pretest*.

Day 2
Students gather in groups of 4-5 to design their own experiments. (*Handout 3: Artesian Well, Part 1 – Design*)

Day 3
Students set up their experiments, run them, collect data, and write their summary and conclusion. (*Handout 4: Artesian Well, Part 2 – Experiment*)

Day 4
Students share their results with class. A teacher led, class discussion about conservation of energy is used to make sense of those results. (*Handout 5: Conservation of Energy*)

Aquifer: A water-bearing layer of rock or sediment capable of holding and transmitting water.

Artesian well: A well produced by drilling into a confined aquifer where the pressure is high enough to cause water to rise above the aquifer.

Clay: A component of rock or soil with particle diameter ranging from 0.00024 – 0.004 mm. Because of the small particle size, clay soils have low porosity and low permeability.

Confined aquifer (or **Artesian aquifer**)**:** An aquifer surrounded by impermeable layers, filled with pressurized water.

Conservation of energy: The total energy in a closed system is conserved. Energy can be transferred or transformed, but the total amount remains constant.

Groundwater: Water stored beneath the earth's surface in open pore spaces and rock fractures.

Impermeable layer: A layer of rock that does not allow water to easily flow through it.

Kinetic energy: Energy associated with an object's motion.

Permeability: The ease with which liquids pass through a material (such as a rock layer).

Porosity: The percentage of the total volume of rock that consists of pore space (the open space between particles or in fractures).

Potential energy (**gravitational energy**)**:** Energy stored in an object due to its position in earth's gravitational field.

Sand: A component of rock or soil with particle diameter ranging from 0.062 – 2.0 mm. Because of the large particle size, sandy soils and sandstones have high porosity and high permeability.

Permeable rock layer: A layer of rock that allows water to easily flow through it. This is also known as an aquifer.

Water cycle: The cyclic transfer of water between earth's atmosphere, bodies of water, and groundwater.

Artesian Well

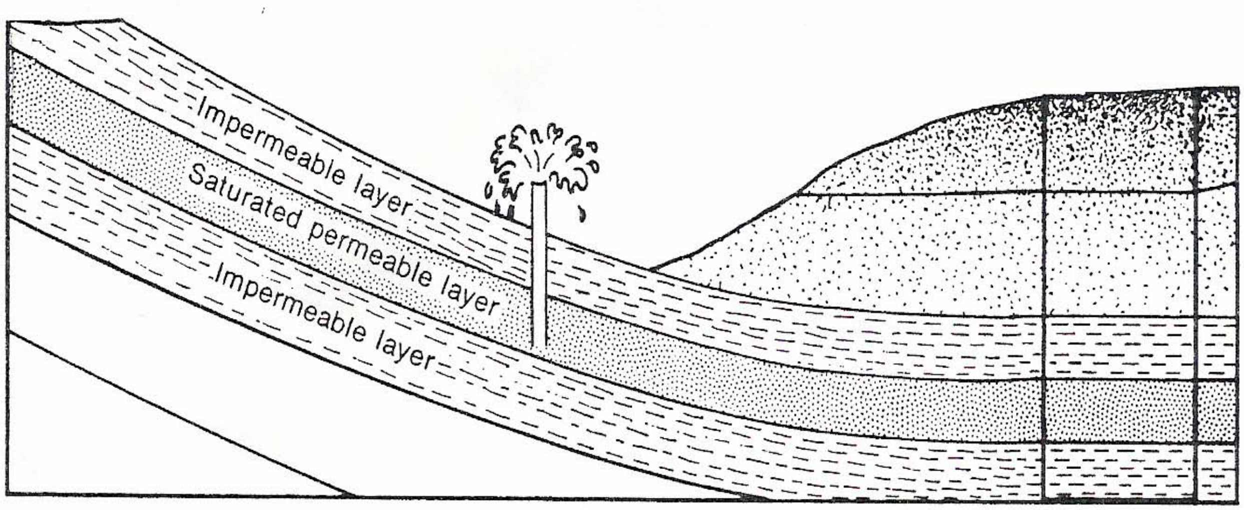
Impermeable layer: A layer of rock that does not allow water to easily flow through it.

Permeable layer: A layer of rock that allows water to easily flow through it. This is also known as an **aquifer**.

Confined aquifer: An aquifer that has impermeable layers above and below it. Confined aquifers are filled with pressurized water.

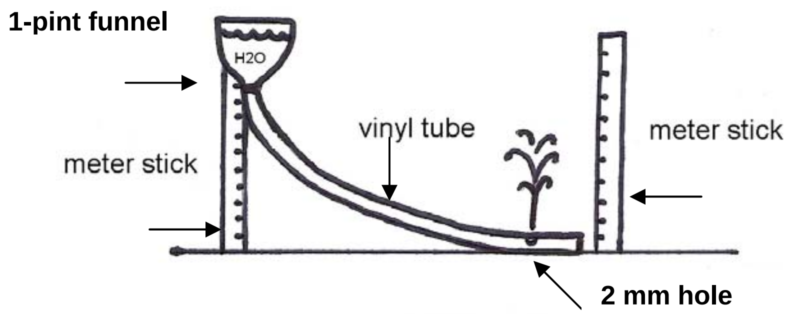
Saturated layer: a layer of rock in which all the pores (open spaces between particles or in fractures) are filled with water.

Artesian well: A well drilled into a confined aquifer. If the water pressure in the confined aquifer is high enough, then water will rise above the land when a well is drilled into it.



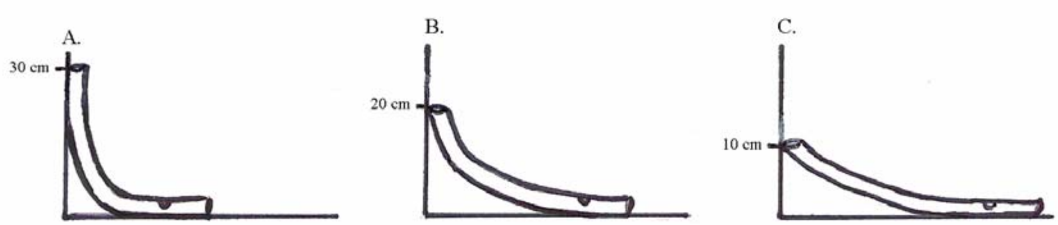
Pretest

We will model an artesian well using flexible, vinyl tubes:

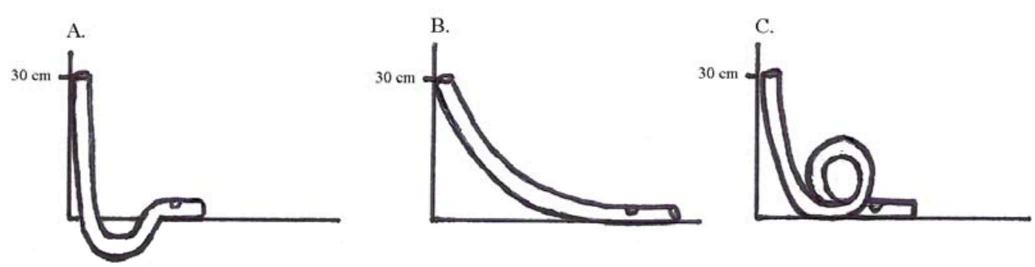


Look carefully at the 3 sets of "wells" below. For each case, predict which will produce the highest fountain of water. Rank them from highest to lowest, for example A>B>C.

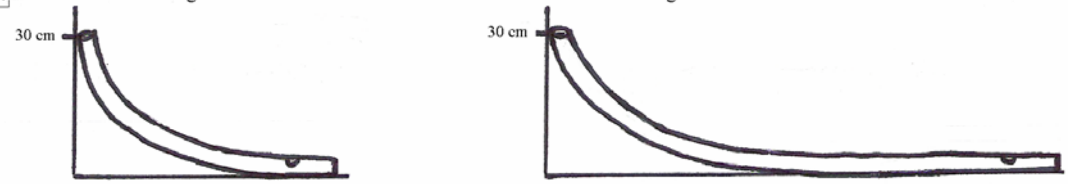
1. All tubes are 50 cm long.



2. All tubes are 60 cm long.



3. A. 60 cm long. B. 100 cm long.



Artesian Well - Design

Earlier you were asked to take the *Artesian Well Pretest*. You predicted which tube, or "well," would produce the highest fountain of water. Now you and your classmates will design your own experiment to test these predictions.

Your group (3 to 4 members) will need to select a **variable** to test. Your variable is the thing that varies, or differs, from one tube to another. For example, in part 1 of the pretest the variable was the *height* of the tubes. In part 2 it was the tubes' *shapes*. In part 3 it was their *lengths*. A proper experiment has only <u>one</u> variable.

Notice that in each case, all other factors were kept constant. For example, in part 1 all of the tubes are of the same length and diameter. They have the same small, 2 mm hole, placed at the same "ground level." Factors such as these that are kept constant are called **controls**.

Design Materials

- Large sheet of poster paper
- Pen, colored pencils, and/or markers

Procedure

1) Decide which variable you want to test. For example, do you want to test the effect tube height has on fountain height? Or perhaps you want to know if the tube's shape makes a difference?
2) How many tubes will you need? (Supplies may be limited! Talk to your teacher about this.)
3) On the large sheet of paper provided to you:
   a) Write down what your variable is, and also tell us what your controls will be.
   b) Write out your hypothesis.
   c) Sketch a simple experimental setup, similar to the pretest, showing how your tubes will be arranged and what their heights and lengths are.

Artesian Well - Design

d) Make a table where you can neatly record the data that you will collect during your experiment. Remember that in a good experiment the hypothesis is tested more than once (multiple "trials") and data is averaged.

4) Explain your experimental design to your teacher and get his/her approval. Make changes if necessary.

Artesian Well - Experiment

Now that you and your partners have designed an artesian well experiment, it is time to construct your set up and test your hypothesis!

Your teacher will have the following **materials** available for you:

- clear, vinyl tubing
- rubber bands
- 2-mm hole punch
- scissors
- meter sticks
- plastic paint trays
- 1-pint funnels
- 200-ml beakers
- water

Procedure

1) Refer to the design poster that you made in your last class.
2) You will need to assign the following duties to your group members:
   - Funnel Holder
   - Tube Holder
   - Water Pourer
   - Data Recorder
3) Use the meter stick and scissors to measure and cut the tubes you will need, adding an extra 2 cm to the length of each. This extra 2 cm will be needed to clamp off one end of each tube.
4) Clamp off one end of each tube by bending over the extra 2 cm and wrapping a rubber band tightly around it.
5) Use the hole punch to make a 2-mm hole in each tube, 3-4 cm from the clamped off ends. Have your teacher supervise this step.
6) Bring at least 600 ml of water to your lab table. You may need more water if your tubes are over 60 cm.

Artesian Well - Experiment

7) Pick one tube to try out first. Snuggly fit the small end of the 1-pint funnel into the open end of your tube.
8) Have the Funnel Holder hold the funnel at the correct height, using a meter stick. (The funnel must remain at this correct height throughout the experiment, so keep the meter stick held up near the funnel throughout the experiment.)
9) Arrange the tube in the shape that you need, with the clamped end in the plastic paint tray. Make sure that the 2-mm hole faces directly upward. The Tube Holder will need to keep the tube in this position throughout the experiment, and will be responsible for monitoring the 2-mm hole. (At times it will be necessary to use a finger to close off this hole to prevent a wet mess!)
10) The Data Recorder should position another meter stick near the 2-mm hole and be ready to measure the height of the fountain.
11) Now that the tube is ready, have the Water Pourer pour water into the funnel until the tube *and* funnel are completely filled with water. You should now observe a fountain of water rising from the 2-mm hole. The Water Pourer will need to add a small amount of water to the funnel every few seconds to maintain a constant water level.
12) The Data Recorder should now measure the height of the fountain and record this measurement in the table you made earlier on your design poster.
13) After a measurement has been taken, the Tube Holder can use a finger to close off the 2-mm hole and stop the water flow. It is recommended that steps 11 and 12 be repeated at least 2 more times so that you can calculate an *average* fountain height.
14) Repeat procedure for remaining tubes.
15) All of your data should now be in the table on your poster, including an average fountain height for each tube. **Are your results what you expected?**

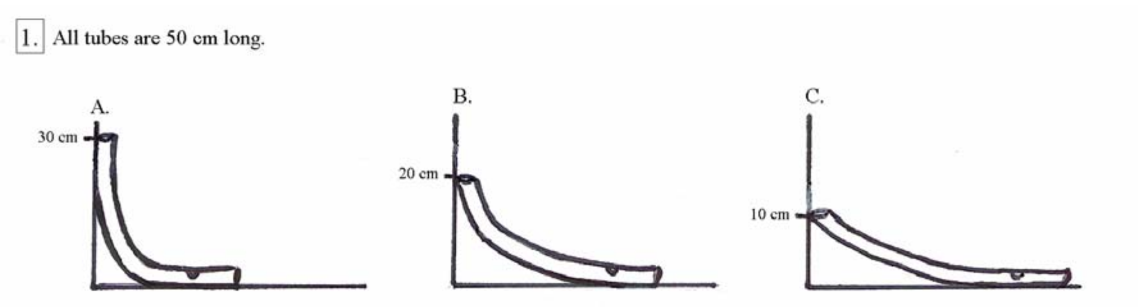
Artesian Well - Experiment

16) Write a brief summary of your results on your poster. Did the data support your hypothesis? If no, what do you think happened? Were your results possibly affected by "human error"? Be prepared to discuss your results with your class.

Conservation of Energy

Remember the *Artesian Well Pretest*? Now that you have observed your own artesian well models in action, you might want to change your earlier answers...

Let's look at Part 1.



The **variable** here is the __________ of the tubes. If this was also *your* variable, then you most likely saw that your **highest tube** produced the **highest fountain of water**.

This is because the water in your funnels had an amount of **gravitational potential energy** equal to the water's weight times its height. In equation form this looks like:

gravitational potential energy = weight **x** height = (mass **x** gravity) **x** height

or

PE = mgh

where PE = gravitational potential energy, m = mass, g = gravity, and h = height.

Conservation of Energy

The mass of the water, "m," in your funnels was the same for all of your models. But if your funnels were at different heights, then the water in them had different values for "h." (The value "g" is a constant value for all objects on earth.)

Look again at the three tubes in Part 1.

- Which tube held the water at the greatest height? __________
- Then which funnel full of water had the greatest potential energy? __________
- Which had the *least*? __________

Now you are probably thinking, "Well that's all fine and dandy, but how does this potential energy stuff explain the *height of the fountains*??"

Maybe you have heard that **energy is conserved**. This means that energy can be *transformed* from one type to another, or *transferred* from one object to another, but it cannot simply disappear or appear out of nowhere. The total amount of energy in a system of objects (or in our universe for that matter) will always remain the same.

As the water in your funnel moved downward, its height decreased ("h" got smaller). That must mean its potential energy got smaller, too. In fact, when the water reached the bottom of the tube (h = 0) it had *no potential energy at all!* But if energy can't disappear, where did it go??

It was *transformed* into another type of energy, one associated with the *motion* of an object, called **kinetic energy**:

kinetic energy = ½ **x** mass **x** velocity **x** velocity

or

$$KE = \frac{1}{2} mv^2$$

Conservation of Energy

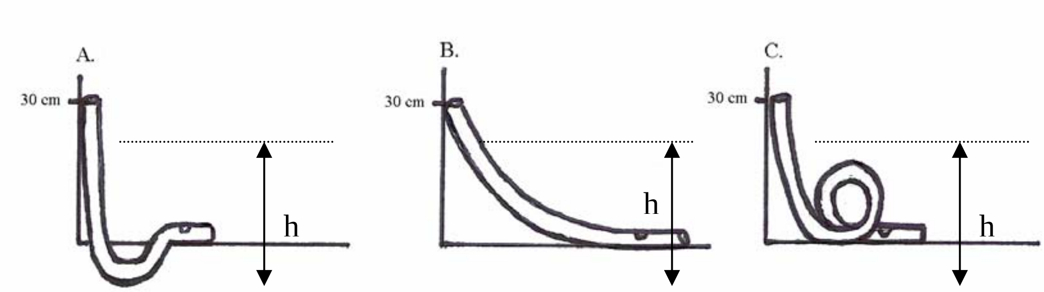
So now you should see water moving with velocity "v" at the bottom of the tube, right? Actually, it *would* be doing just that if we hadn't clamped off the end of the tube. In fact, if the 2-mm hole is also closed, then the water is completely trapped in the bottom of the tube, stopped in its tracks—**and** under pressure from the weight of the water above it (water still in the top part of the tube and in the funnel). This condition of trapped, pressurized water is how we defined a **confined aquifer**, remember? Opening the 2-mm hole is similar to drilling a well—an artesian well.

Because we have the hole pointed directly upward, the water will, of course, go straight up. But *how high* will it go? Can we correctly predict how high? Yes, we can, because of the **conservation of energy**! Remember, the kinetic energy at the bottom of the tube can't simply disappear. You can probably guess what happens to it—just like before, it is *transformed* into a different type of energy, one based on height—potential energy!

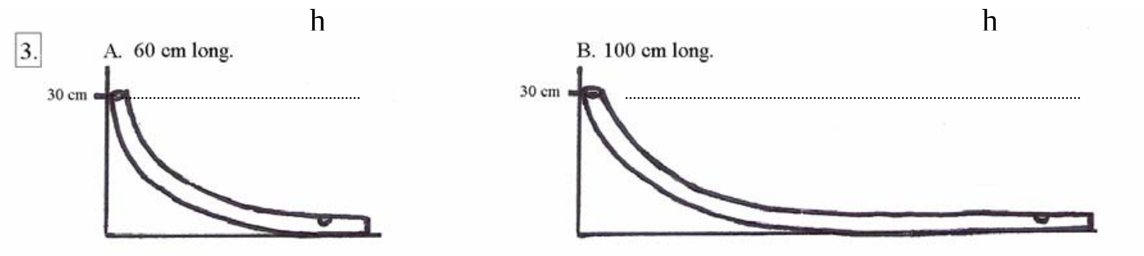
Amazingly, the height of the fountain will be exactly the same height as the water's starting point (the height of the funnel)!

Now let's take a look at Parts 2 and 3 of the Pretest:

2. All tubes are 60 cm long.



Conservation of Energy



<u>All</u> of the tubes have the same "h."

Then, knowing that potential energy is a function **only** of height, "h," and knowing about conservation of energy…

Can you predict which tube(s) will produce the highest fountain of water??