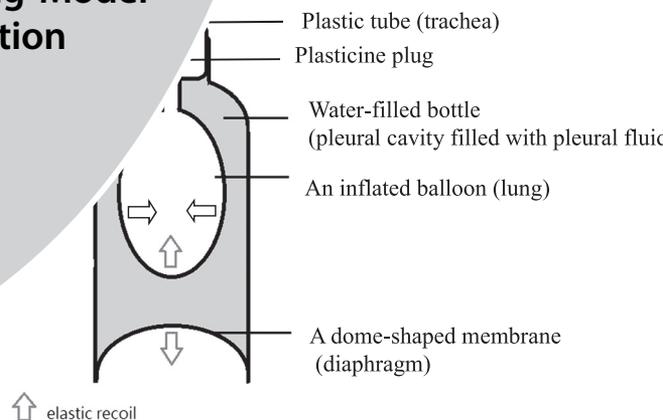


An Improved Physical Lung Model for Teaching Lung Ventilation

• KWOK-CHI LAU



ABSTRACT

This article describes an easily made physical lung model for teaching about lung ventilation. It has rectified some major shortcomings of the bell-jar balloon model by having a fluid-filled “pleural cavity,” a dome-shaped “diaphragm,” and an inflated “lung” at rest. The model can be used to tackle some misconceptions about ventilation as well as to learn some difficult concepts such as the negative pleural pressure and pneumothorax.

Key Words: model; lungs; ventilation.

○ Introduction

Physical lung models are commonly used to teach about ventilation in lungs. As an external physical entity, the model can facilitate learning by making abstract ideas visible and reducing the mental resources needed to process the information (Rapp & Kurby, 2008). In addition, the process of making the lung model is also relevant to one of the Science and Engineering Practices of the *Next Generation Science Standards* (NGSS Lead States, 2013) – building models to describe and explain natural phenomena and work out design. It serves as a STEM activity to foster students’ abilities in problem solving and integration of science knowledge.

The most commonly used lung model is the bell-jar balloon model (Mayow, 1957). Teachers typically use the model to show inhalation by pulling down the rubber sheet and exhalation by pushing up the rubber sheet (Figure 1). This model, however, may cause several misconceptions. First, the model’s “diaphragm” is flat at rest and is pulled downward to show inhalation (Figure 1). This is different from the human lungs, whose diaphragm is dome-shaped at rest and moves downward to become flattened during inhalation. Second, the bell jar does not move as the rib cage does during breathing. In a test for 33 sixth-graders, 87% of students erroneously described the diaphragm as being flat after exhalation and concave at the end of inhalation, while 58% did not explain breathing with the chest movement (Eilam, 2013).

Third, the bell jar is air-filled, but in human lungs the space between the lungs and the thorax is the fluid-filled pleural cavity (Sherman, 1993; Yip, 1998). Because of the compressibility of air, the balloons in the bell jar will not expand effectively in response to the movement of the diaphragm. Fourth, the balloons of the model are nearly fully deflated at rest. But in humans, the lungs are inflated to some extent at the end of exhalation (residual volume) because the elastic recoil of the lungs is being balanced by the subatmospheric pleural pressure (Widmaier et al., 2008).

Yip (1998) and Sherman (1993) had attempted to rectify the above problems. Sherman’s model has an inflated balloon in a water-filled bottle, but the model falls short in that it is operated by a syringe rather than a diaphragm. Yip improved the bell-jar model by making the bell jar water-filled, but the rubber sheet is bulging downward at rest rather than dome-shaped. Neither study provides the procedure to make the models.

○ An Improved Lung Model

The lung model proposed here is unique in having an inflated “lung” (balloon) at rest, a water-filled “pleural cavity,” and a dome-shaped “diaphragm” (Figure 2). The elastic recoil of the balloon is balanced by that of the diaphragm, creating a subatmospheric pressure inside the water-filled bottle. The model thus accurately simulates the anatomical states and the physical conditions of our breathing system. The procedure is illustrated in Figure 3 and outlined below in five steps. It requires only simple tools and materials, making the model construction an interesting STEM activity even in elementary classrooms.

○ Procedure for Making the Lung Model

1. Insert a plastic tube into the neck of a balloon and fasten it with an elastic band. Put the balloon in a plastic bottle with the bottom cut. Wrap the mouth of the bottle with plasticine.

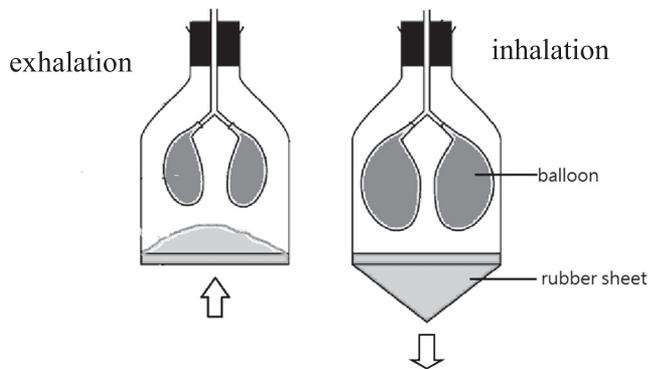


Figure 1. The bell-jar balloon model.

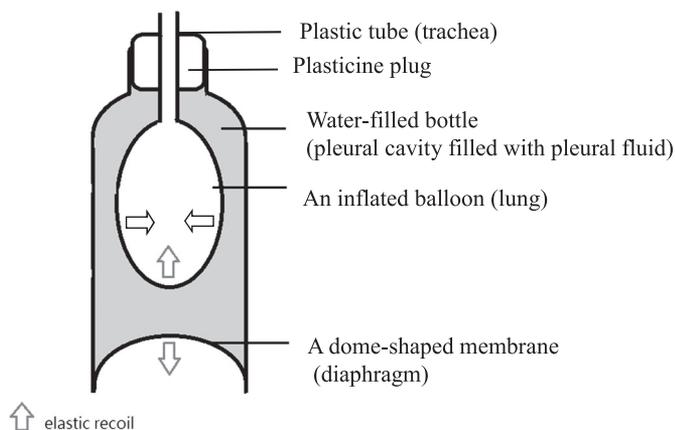


Figure 2. An improved lung model showing the inflated balloon and dome-shaped “diaphragm” at rest.

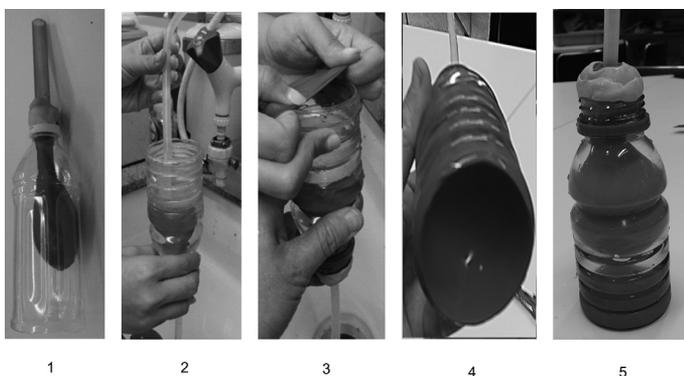


Figure 3. Procedure for making the lung model in five steps.

2. Blow up the balloon through the plastic tube. Bend the plastic tube or twist the balloon neck temporarily and then plug the tube with plasticine. The balloon is now kept in an inflated state. Fill up all the space between the balloon and the bottle with water in the sink.
3. Cover up the bottom of the bottle with a half-cut balloon membrane. Try to avoid leaving any air inside the bottle. Use adhesive tape to fix the membrane at the bottom.

4. Remove the plasticine plug of the plastic tube. The balloon inside the bottle will shrink a little by elastic recoil, making the diaphragm at the bottom dome-shaped.
5. The model is now finished, with an inflated balloon in a water-filled bottle and a dome-shaped diaphragm.

Instructional Ideas with the Model

To teach pulmonary ventilation with the lung model, students in small groups are first given the model to manipulate and then asked the following questions:

- How is the balloon kept inflated at rest?
- How is the diaphragm kept dome-shaped at rest?
- Why does the balloon expand when the diaphragm is pulled down?
- How does the air enter the balloon?

Students need to apply the concepts of Boyle’s law and elastic recoil in their interpretations. After they understand the working of the lung model, students need to go further and explain how the model simulates our ventilation mechanism. Some misconceptions are tackled here. First, exhalation is usually brought about by passive elastic recoil of the lungs and the diaphragm, rather than by active pushing up of the diaphragm (Widmaier et al., 2008). Second, there is no air between the lungs and the thoracic wall, but rather pleural fluid that connects the lungs with the thorax. When the thorax expands or contracts, the lung will change its size correspondingly due to the incompressibility of fluid. Third, the diaphragm is dome-shaped at the end of exhalation and never bulges downward.

Students have to critically appraise the limitations of the lung model as an external representation of our breathing system. One important limitation is that we breathe by using both the thoracic wall and the diaphragm, but the lung model works with a diaphragm only. One main anatomical limitation of the model is that it is made of one tube and one balloon, which represents only one of hundreds of millions of alveolar sacs connected by a network of tubes in the lungs. More able students can be challenged to predict what will happen to the model when the bottle is punctured. The balloon will collapse by elastic recoil and remain deflated no matter how much the diaphragm moves. This is because the pressure inside the bottle changes from subatmospheric to atmospheric, and the diaphragm can no longer change the pressure inside the bottle. It illustrates the difficult concept of pneumothorax, in which the lungs collapse when air enters the pleural cavity. To test if the prediction is correct, students can use a needle to pierce through the plasticine cap at the bottle mouth.

Apart from learning the concepts, the construction of the lung model itself is an interesting and challenging STEM activity. One challenge is to make the bottle water-filled while the balloon is kept inflated. It requires students to have high problem-solving abilities and hands-on skills. The design process of planning, making a protocol, testing, and revising can be introduced here. In a professional development course for biology teachers, the participants were shown the model and asked to make it without any instruction. The teachers came up with a variety of innovative solutions, but only a handful of them could make it in the end.

○ Conclusions

The lung model described here is superior to the traditional bell-jar balloon model in that it includes a dome-shaped “diaphragm,” an inflated “lung” at rest, and a fluid-filled “pleural cavity.” It models how subatmospheric pressure is built in the pleural cavity by the elastic recoil of the lungs. The model construction itself constitutes a fun and challenging activity for students, in which many concepts of physics and biology are called upon. A teacher’s guide to making the model and using it instructionally is provided in the Supplemental Material available with the online version of this article.

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