

# An Educational Model for Teaching the Gas Laws

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## Abstract

The Gas Laws are a series of Laws governing the behaviour of a gas under different conditions, and are typically taught to high school students studying physics. A student's understanding of these laws can be greatly enhanced through experiment. This report describes a model designed to allow a user to conduct a series of virtual experiments on a gas, and to observe how a gas behaves under certain conditions.

Please note that the proposed weighting for the model and paper is 50%:50%.

## 1 Introduction

Empirical Modelling has been successfully applied many times in the past to an educational context [3],[1]. Previous research has indicated that EM is well suited to supporting learning activities, enabling learning through experimentation and interaction with artifacts in a model.

This modelling study describes a model to enable students to learn about the set of laws governing the temperature, pressure and volume of a gas. These laws, including the ideal gas law, Boyles law and the combined gas law, describe the relationship between the temperature, pressure and volume of a gas, and are typically taught to high school students studying physics. A student's understanding of these laws can be greatly enhanced by experimenting with a gas, changing a certain property such as temperature, and observing the consequence this change has on the state of the gas. Such experiments, however, can be difficult to perform in the classroom.

The proposed model provides a number of virtual experiments in which a student can interact with a 'virtual gas', changing properties such as temperature, pressure or volume, and observing the consequences these changes have on the gas and its environment.

Interaction with the virtual experiments takes place through a graphical user interface. A two or three-dimensional visualisation accompanies each virtual experiment, helping the student to understand the experiment and allowing them to observe the consequences of any changes of state.

In addition to describing what the model itself will contain, the modelling study examines the advan-

tages an empirical model has over a traditional, physical laboratory-based experiment. It also looks at how an EM-based implementation compares to a traditional programming approach, and examines how suitable the existing EM tools are for implementing the model.

## 2 Experiments and EM concepts

The links between EM and education are well defined, and EM models have successfully been used many times in the past to facilitate learning of a particular subject [3],[1].

The constructionist theory of learning proposes that we learn by actively constructing mental models of the world around them. This theory of learning is well aligned with EM concepts and the concept of the virtual experiment [2]. In the virtual experiment, the user is able to interact with the model, observing the effect of any input. In this way the user can construct their own mental model of the system and its behaviour.

## 3 The Model

### 3.1 Pre-Implementation

It was originally envisaged that the model would simulate the interaction of individual gas molecules, tracking their location in two or three dimensions. A suggestion was made that this kind of interaction could be seen as a natural extension of the billiardsYung model. Unfortunately, modelling such large numbers of interacting molecules in Eden was not an easy task, and in preliminary tests, the performance of the model was not good enough to allow any meaningful observation from the user.

Instead, it was decided that a simpler approach should be taken – instead of modelling the interaction of individual particles, the model simply maintains the state of certain key properties of the gas, with scope for the user to change these properties and observe the outcome. This approach still fulfils the objectives of the model.

## 3.2 Interaction

The model allows for the user to interact with three different and distinct virtual experiments. Each of these virtual experiments is designed to allow the user to learn about a key gas law. A SCOUT interface provides the user with a means of interacting with each experiment, and observing the output. Each experiment is accompanied by a text-based readout of the relevant properties of the gas, and when appropriate, a DoNaLD drawing is provided to give the user some meaningful visual feedback.

### 3.2.1 Boyle's Law

Boyle's Law describes the relationship between the pressure and volume of a gas –  $PV = k$ . A common experiment performed in classrooms is to submerge a gas-filled balloon in water, noting how the change of pressure affects the volume of the balloon. The model presents a virtual version of this experiment (see Figure 1), allowing the user to change the depth of a spherical balloon and observe the resulting change of the volume (and therefore diameter) of the balloon. The SCOUT interface provides two click-able buttons – one to raise the balloon and one to lower it. Dependency is used to maintain the volume following a change in pressure.

### 3.2.2 Charles's Law

Charles's Law describes the relationship between the temperature and volume of a gas –  $V = kT$ . Again, the model presents an experiment to allow the user to explore the properties of the law. In this experiment (see Figure 2), the user is able to change the temperature of a spherical gas-filled balloon, and to observe the consequences of this change on the volume of the balloon. A graphical simulation of a thermometer is also provided, along with a two-dimensional drawing of the balloon and click-able buttons allowing the user to raise or lower the temperature. This experiment is similar to ones which could be performed in a classroom. As with the Boyle's Law experiment, dependency is used to maintain the volume of the gas following a change in temperature.

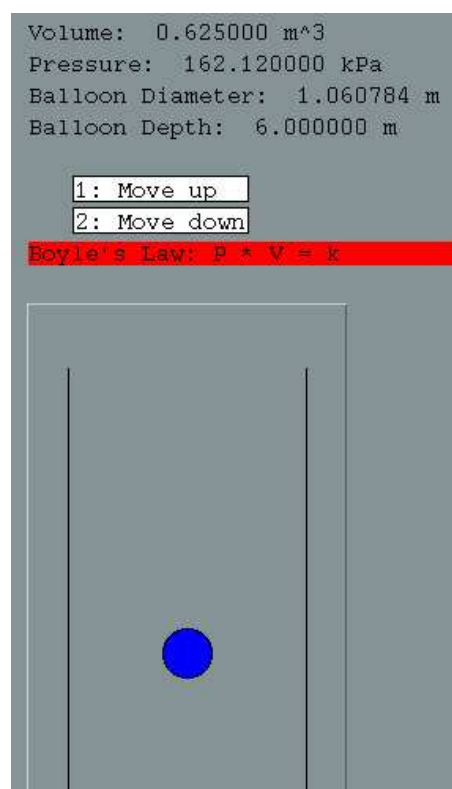


Figure 1: The Boyle's Law experiment

### 3.2.3 The Ideal Gas Law

The Ideal Gas Law describes the relationship between Pressure, Temperature, Volume and number of molecules of a so-called ideal gas –  $PV = nRT$ . The presented experiment (see Figure 3) allows the user to observe the effects of this law on a gas in either a fixed-sized container or a flexible balloon. The user is able to select the type of vessel in which the gas is contained – either a flexible balloon or rigid box. The user is able to adjust the one property of the gas at a time, and can then observe the resulting effect on the other properties. For the balloon, we assume that the volume of the gas will expand or contract to keep the pressure constant, while for the rigid box we assume that the pressure will change while the volume remains constant. This is a somewhat naive assumption, however; in reality the balloon will expand to a certain point, and will then burst.

Unlike with the previous experiments, we are unable to use dependency to maintain the properties of the gas due to circular dependency issues. Instead, we define procedure calls to change the state of each property. Whilst this procedural nature of changing properties is somewhat contrary to the EM approach,

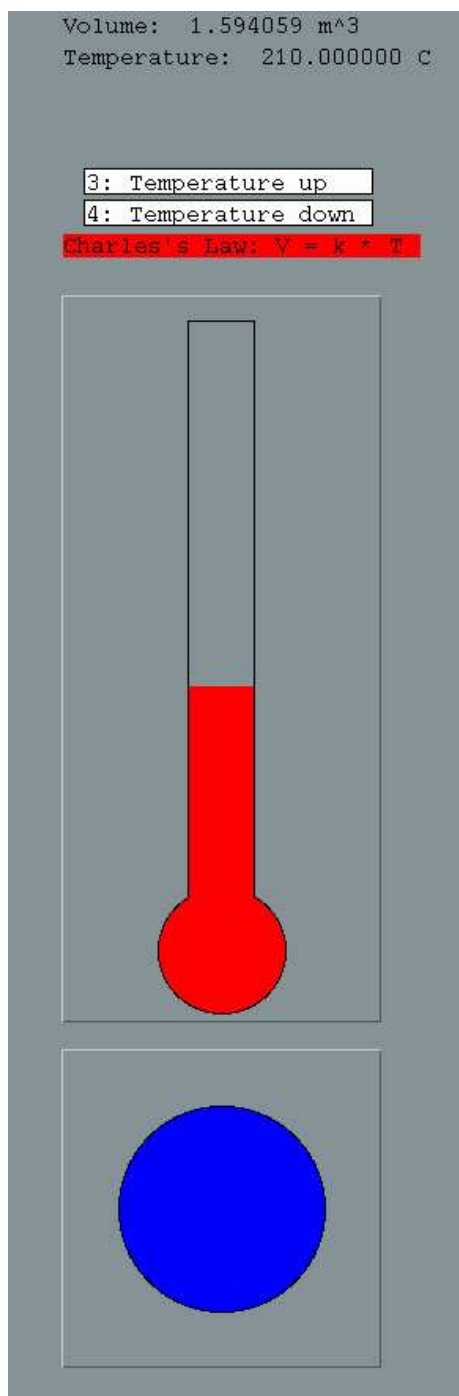


Figure 2: The Charles's Law experiment

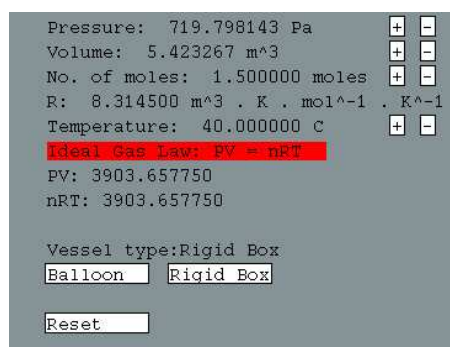


Figure 3: The Ideal Gas Law experiment

it seems to be the only way of maintaining the different properties.

Note that the model is somewhat unrealistic in how it calculates how the properties of the gas will change. In the current implementation, a change to one property of the gas will only result in a change in one other property to compensate. In reality, it is likely that many properties would change – e.g. a change in volume may result in a change in pressure and temperature. Unfortunately it is very difficult to calculate what these changes are, though modelling the interaction of the individual gas particles as was originally envisaged would perhaps have solved this.

### 3.3 Benefits of the model

The virtual experiments provided by the model have several advantages over the real experiments that students would typically conduct.

**Ease of use:** Unlike a real experiment, where specialist equipment and preparation time is required, the virtual experiments are always available to use. Users can instantly start to explore the model, and there is no possibility for error by misusing or misreading any measuring equipment.

**Flexibility:** When conducting experiments in a classroom environment, students would typically be able to explore the properties of a gas under a fairly limited range of values. Extreme temperatures or pressures could not generally be achieved. In the virtual experiment, however, a user is free to explore how a gas will behave in any condition, no matter how extreme.

In addition, if the user wished to, they could alter the model and redefine a gas law to explore how a gas would behave in such a situation. Obviously, in a

classroom governed by the laws of physics, this could not happen.

### 3.4 Suitability of Tkeden

As previously mentioned, it was originally envisioned that the model would model the interaction of individual gas particles, though this proved difficult to achieve in tkeden. The use of a more powerful scientific language, such as Fortran, could perhaps have made this possible.

The revised model, however, was fairly easy to implement in tkeden, and the use of dependency ensured that, when necessary, the gas properties were updated automatically.

Whilst a similar model could have quite easily been implemented in a language such as Java, tkeden allows for the user to use the interpreter window to explore and change the state of the model beyond what is possible with the user interface.

### 3.5 Future Expansion

In its current state the model is very limited. The restricted nature of user interaction (through a simple point-and-click interface) and the limited nature of the output (text-based readouts and simple two-dimensional drawings) means that the level of involvement and interpretation from the user is limited. A number of possible improvements have been identified, and could be implemented in future revisions of the model.

#### 3.5.1 User Input

Currently, the way the user interacts with the model is very limited – click-able buttons are presented in a SCOUT window, and the gas properties are changed by clicking on the buttons. The user can use the Eden interpreter to change and update values in a more open way, though a detailed knowledge of the model would be required to achieve this. A more intuitive user interface would be beneficial, perhaps incorporating sliders that the user can drag using the mouse.

#### 3.5.2 Output

The way in which the model presents its state to the user is very simple – text based readouts and two-dimensional drawings. Whilst this presentation of information is somewhat effective, with the exception of the thermometer visualisation, it does not resemble what would be seen in a real experiment. More effort could perhaps be put into creating more

visualisations of measuring apparatus, such as an analogue meter to measure pressure or a ruler to indirectly measure the volume of the balloon. In addition to two-dimensional drawings, a three-dimensional visualisation could be added using Sasami, allowing for a more realistic representation of what would be seen if the experiment were to be performed in real life.

#### 3.5.3 Extensibility

Currently only three experiments are provided. Whilst this gives the user a chance to learn about three different gas laws, there are a number of other experiments which could be added to enhance the user's experience. A teacher or student could achieve this by adapting one of the current experiments, though unfortunately the lack of objects and classes in tkeden makes extending existing models a somewhat arduous task.

## 4 Conclusion

The model is somewhat successful. By allowing a user to conduct virtual experiments, they are able to construct their own mental models of the behaviour of a gas under different conditions. However, the simple and limited nature of the input and output means that EM is perhaps not used to the best extent in this model, and a number of potential improvements have been recognised. However, even in its current state, the model can still be used as a valuable teaching aid.

## References

- [1] Beynon, M. Empirical Modelling for Educational Technology
- [2] Beynon, M., Roe, C. Computer Support for Constructionism in Context
- [3] An Educational Model for Newtonian Mechanics, WEB-EM-02