Conclusion

The 'ions in a sea of electrons' model was put forward at a time before it could be really tested by experiment. It is unable to account for the varied properties of metals, and the 'explanations' offered in textbooks are misleading and in some cases at odds with topics in physics. Recent work provides overwhelming evidence that it is not a good representation of metallic bonding and structure. The soft sphere model is a good alternative model that accounts for many metallic properties. Soft sphere derived equations produce good agreement between calculated and observed values of lattice energies, work functions, densities, enthalpies of formation (of usually the most stable M^{x+} ions), electrical resistivities and coefficients of expansion. Hence this alternative model is more suited to explaining metallic bonding to chemistry students. Box 2 illustrates some of the values calculated by a soft sphere derived equation and the good agreement between the values calculated and published literature values.

References

Lang, P. F. (2017) An investigation into some important properties of transition metals. *Chemical Physics Letters*, **690**, 5–13.

Lang, P. F. (2018) Is a metal 'ions in a sea of electrons?'. *Journal of Chemical Education*, **95**(10), 1787–1793.

Lang, P. F. and Smith B. C. (2003) Ionisation energies of atoms and atomic ions. *Journal of Chemical Education*, **80**, 938–946.

Lang, P. F. and Smith B. C. (2010a) Ionic radii for Group 1 and Group 2 halide, hydride, fluoride, oxide, sulphide, selenide and telluride crystals. *Dalton Transactions*, **39**, 7786–7791.

Lang, P. F. and Smith B. C. (2010b) Ionisation energies of lanthanides. *Journal of Chemical Education*, **87**, 875–881.

Lang, P. F. and Smith B. C. (2014a) A new model of metallic structure and bonding. *European Chemical Bulletin*, **3**(4), 390–395.

Lang, P. F. and Smith B. C. (2014b) Electronegativity effects and single covalent bond lengths of molecules in the gas phase. *Dalton Transactions*, **43**, 8016–8025.

Lang, P. F. and Smith B. C. (2015) An equation to calculate internuclear distances of covalent, ionic and metallic lattices. *Physical Chemistry Chemical Physics*, **17**, 3355–3369.

Ma, Y., Eremets, M., Oganov, A. R., Xie, Y., Trojan, I., Medvedev, S., Lyakhov, A. O., Valle, M., Prakapenka, V. (2009) Transparent dense phase sodium. *Nature*, **458**(7235), 182–185.

Pauling, L. (1967) *The Chemical Bond*. Ithaca: Cornell University Press.

U.S. Department of Commerce, National Bureau of Standards and Joint Committee on Powder Diffraction Standards (1973) *Crystal Data Determinative Tables*. 3rd edn. Washington, DC,

Yick, H. and Laird R. (2017) Intermolecular forces. *School Science Review*, **98**(364), 16–18.

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Investigating friction and checking the understanding of variables using toys that both engage interest and promote understanding

Catherine Dunn

Using toys in class can improve both engagement and learning. If the lesson requires the use of a toy to generate results that can then be processed, I have found that students eagerly set about the experiment and happily do the data processing required. The small toys used here can illustrate the importance of friction when walking.

Pupils often have difficulty with variables at secondary level. They need practice at data processing. This simple experiment generates data easily and enables the experimental and data processing skills of the pupils to be assessed. They need to be able to identify the variables, check their results are reproducible, find the mean from a set of measurements and then display their findings using the correct type of graph. The experiment could be used for key stage 2, year 5 (ages 9–10), where the force of friction is mentioned in the curriculum, or at secondary level in year 7 (ages 11–12), when investigating how friction affects the motion of an object, as stipulated by the *Sciences: Experiences and Outcomes* in Scotland (Education Scotland, no date).

Raising attainment can be achieved using formative assessment (Black and Harrison, 2004). This experiment facilitates formative assessment because pupils can discuss the results with the teacher as they carry out the experiment.

To introduce the experiment, wind up (equally) the two clockwork toys and place them on the bench (Figure 1). When they are released, one will walk away and the other will stay put (Figure 2). Ask pupils to explain why this happened. When the pupils look at the

Figure 1 Two clockwork toys, one with felt 'shoes' and one without

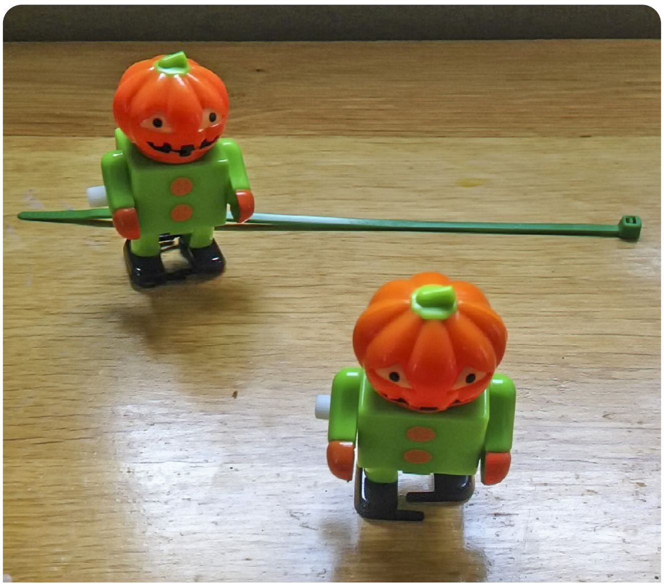

Figure 2 The clockwork toy with no shoes wins the race

toys' feet, they will see that one toy has felt 'shoes'. This introduces the concept of friction and reinforces the need for friction between two surfaces in order to be able to walk across a surface. The toy with felt shoes on had insufficient friction to enable it to walk (Figure 3). This demonstration has been adapted to make an investigation suitable for primary or secondary school children.

Figure 3 Illustrating the felt pads ('shoes') on one toy compared with an identical toy without shoes

This experiment enables pupils to investigate how the frictional force between two surfaces affects how far a toy dinosaur can walk up a ramp. The apparatus required is a 30 cm length of electric cable trunking of width 25 mm, a toy dinosaur, glue dots, two pieces of 5 mm thick wood and samples of material from which to make shoes for the dinosaur. There are different species of toy dinosaur available (Figure 4).

Before they start, pupils should discuss what they need to do in order to make the experiment a 'fair test' and how they will control variables. For example, pupils should state that they will use the same dinosaur throughout, and that they will control variables such as the ramp height; ramp height is controlled by placing

Figure 4 The different species of dinosaur used for observing climbing up a ramp

the trunking on a piece of A4 paper so that its ends are directly above the ends of the paper, with the piece of wood always against one end of the paper (Figure 5).

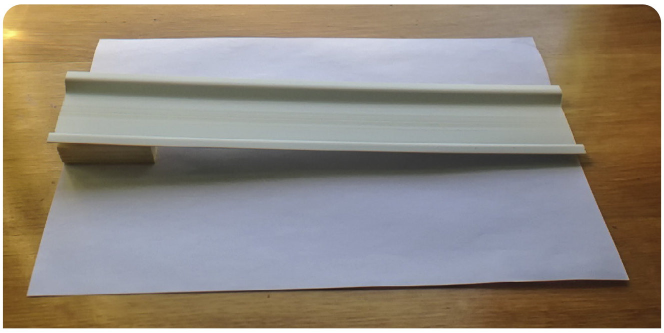

Figure 5 The ramp in place and ready to use; note that each end of the ramp is above the edge of the paper so that the ramp can be returned to its original position if displaced

If anyone knocks the ramp, it can be returned to its original position and the experiment can be completed without having to redo the previous results. The surface that the dinosaur walks on is the same throughout. The variable that is changed, the independent variable, is what shoes the dinosaur wears. This is an example of a categoric variable. The variable that is measured, the dependent variable, is how far the dinosaur gets up the ramp. The dinosaur must not be over wound – three turns should be enough. The number of turns used must be the same throughout the experiment. Wind up the dinosaur and place the dinosaur with all its feet on the bottom of the ramp. Release the dinosaur and see how far it goes up the ramp (Figure 6). As it is difficult to clean the trunking quickly for another lesson if the pencil mark is made on the trunking itself, mark the position the dinosaur reaches on the sheet of paper.

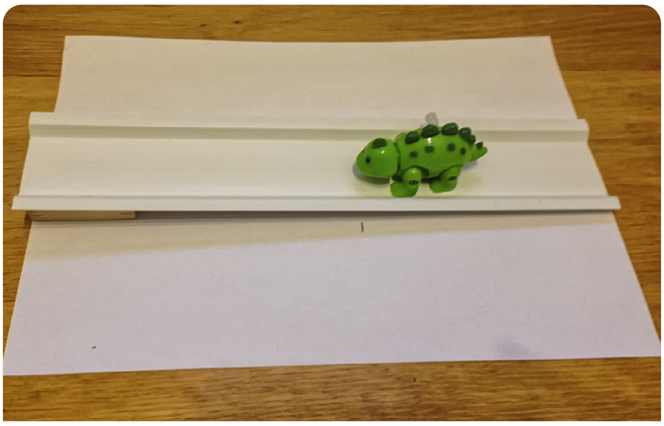

Figure 6 The dinosaur with no shoes on made it this far up the ramp (note the pencil mark on the paper below the front of its head)

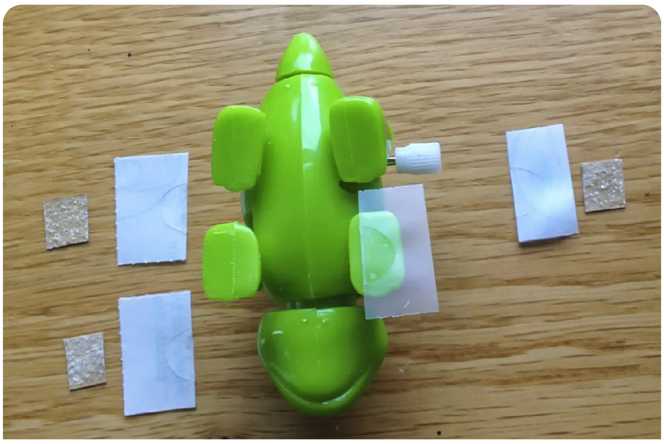

Figure 7 Stick half a glue dot to each foot

Adjust the height of the ramp (using different blocks as needed) so that the dinosaur makes it about a third of the way up the ramp. The challenge is to get shoe soles that enable the dinosaur to get further up the ramp.

Shoes are attached to the dinosaur using glue dots. Cut a glue dot in half and remove the paper from one side. Place the sticky side of the half glue dot on one of the dinosaur's feet (Figure 7). Repeat for the other feet. Be sure not to let the glue dots overlap the edges of the feet.

Cut the material you are going to test for the shoes so that each piece just covers the glue dot (making sure not to overlap the feet) and then place the material on top of the glue dot (Figure 8).

Wind up the dinosaur with three complete turns and place it at the bottom of the ramp as before. Release the dinosaur and see how far it gets up the ramp. Repeat the experiment at least twice to check that the results are reproducible.

This experiment shows how necessary it is to have friction between two surfaces if the dinosaur is to walk up a ramp. The greater the frictional force between the two surfaces, the further the dinosaur makes it up the ramp as there is less slippage.

A bar graph (Figure 9) should be used because the selected material is a categoric independent variable. The bar graph shows that, for this set-up, the sandpaper shoes were the best as the dinosaur got the furthest up the ramp with the sandpaper shoes on.

This experiment requires little preparation but enables the understanding of variables and how to present data to be assessed in an engaging manner. The need to repeat the experiment to check the reproducibility of data and to find a mean can lead to discussion of errors.

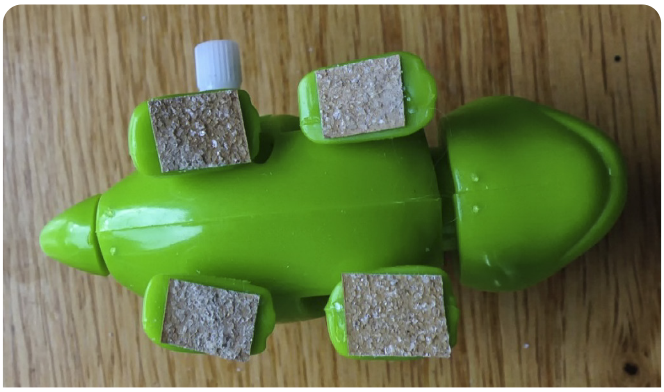

Figure 8 The dinosaur fitted with sandpaper shoes

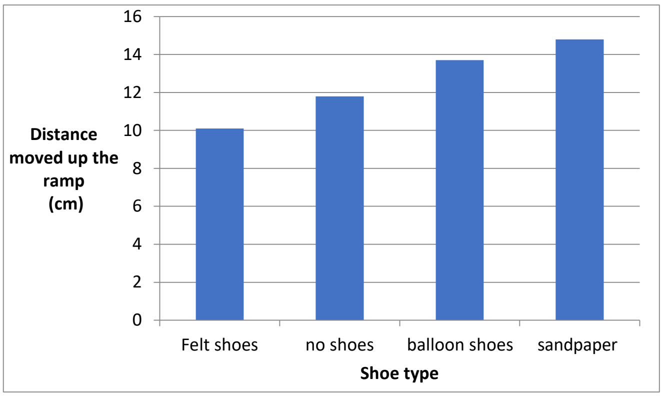

Figure 9 The bar chart compares how far the dinosaur moved up the ramp using different shoes

If doing this at primary level, the experiment can be adapted accordingly.

References

Black, P. and Harrison, C. (2004) *Science Inside the Black Box: Assessment for Learning in the Science Classroom*. London: NFER.

Education Scotland (n.d.) *Sciences: Experiences and Outcomes*. Education Scotland. Available at: https://education.gov.scot/media/jcxpmwd5/sciences-eo.pdf.

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