Electric circuit model using water

Voltage is a difficult idea. This analogue was developed to help formulate the concept. The model uses the vertical dimension to represent voltage. The flow of water in that part of the model that represents the circuit is entirely in the horizontal plane. Current and voltage are modelled by fluid flow and water levels respectively.

Introduction

You can see from the illustration (Figure 1) that the circuit lies on a large cream-coloured plastic tray sitting on a dark grey plastic box. The box is filled with water and represents the electrical earth - or a near-infinite supply of charged particles. The tall translucent plastic food container represents the battery. To charge the battery, there is a 12 V submersible pump submerged in water in the grey box. The pump is operated by a hand-cranked generator (PASCO, EM-8090). The effort required to operate this to completely recharge the battery, is enough to tire you out. The model therefore gives you the feeling that work has to be done for current to flow; i.e. it provides a kinaesthetic learning experience. A hand-operated lift pump was also tried, but rejected because it delivered water in large dollops.

Electrical wiring is represented by pvc bubble-tubing (1/4″ ID, 3/8″ OD); the bubble feature lets the tube fit securely on any component that does not have this exact size. The 1/4″ ID size was determined by the flow indicator. Were it not for this, a smaller ID sized tubing might be preferable.

There are two horizontal rods set up across the tray at a height of 40 cm above the plane of the circuit. Bossheads on these rods support the three manometer tubes and the water inlet to the battery tank. The battery tank is on a lab jack. Its outlet is set at about tray-height and it holds water to a depth of 28 cm. The water outlet is a valved-coupling with hosebarb. In fitting it, the plastic wall was drilled with a chassis cutter to ensure that the joint does not leak. Downstream (Fig. 2) there are the following components in series - the analogous electrical component is shown in brackets:

- T-piece, with 40 cm manometer tube (voltmeter) ;
- Keck clamp (blue) (variable resistor or switch)
- T-piece, with 40 cm manometer tube (voltmeter);
- Roto-flo indicator (ammeter) ;
- Screw clamp (variable resistor or switch)
- T-piece, with 40 cm manometer tube (voltmeter)
- Outlet to large box (earth or ground)

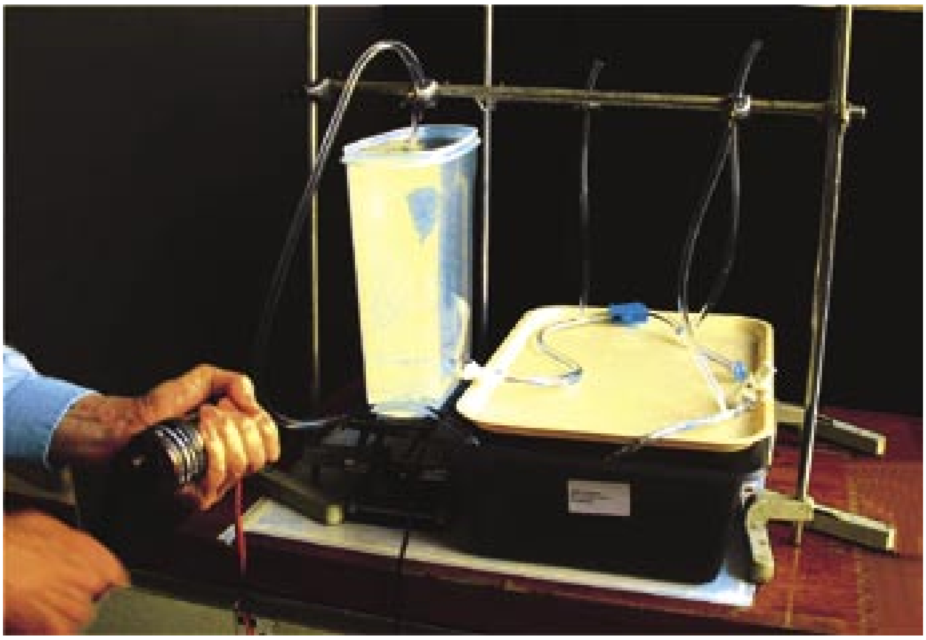

Figure 1 - Electric circuit model using water

Two different types of clamp (Keck and screw) were used in the trials and both were effective. Whether you standardize on one type, or get two types for the sake of variety, is a matter of choice. Different styles of clamp merely reflects different types of resistor – but this may only confuse some pupils.

Advantages - satisfactory features

- Water current can be raised or lowered by controlling the variable resistors.
- Manometer-tube levels satisfactorily show the expected potentials around the circuit. The first level is lower than the battery-tank level because of the pressure difference across the valved outlet (representing the 'lost volts'). The second level is lower still, and its height can be raised or lowered by adjusting one or other of the resistors in the potential divider. The third level is tray height, or ground.
- When one of the clamps shuts off the flow, the system represents an open circuit, or static electricity. The manometer levels upfield of the clamp are equivalent to the battery-box level. The manometer levels downfield of the clamp are at ground level.

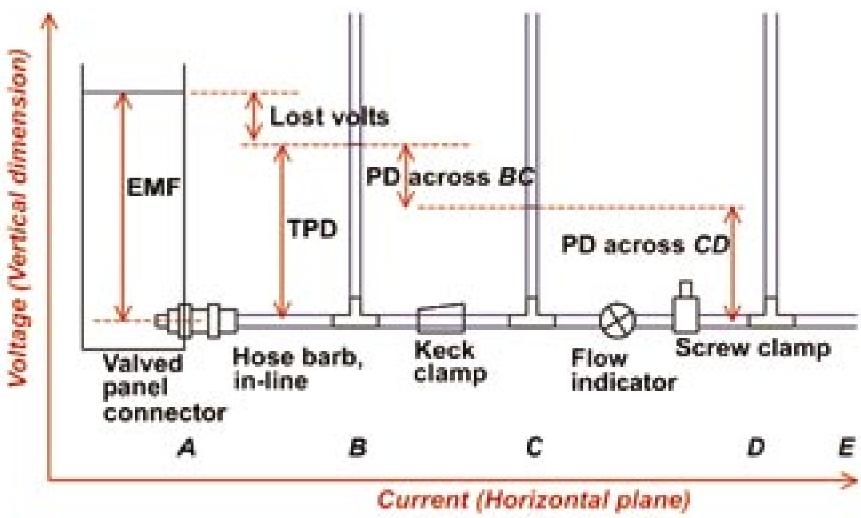

Figure 2 - Components and representation of electrical quantities

Disdvantages - unsatisfactory features

- The flow-rate wheel does not turn when the water flow is very low.

- The water flow has to be low for the desired water-tube levels. If the water flow-rate is high, the water wheel turns fast (which is satisfactory), but there is a significant pressure drop across lengths of tubing. Electrically, this is equivalent to placing a 0.5 ohm resistor in a circuit where the resistance of the wires is about 0.2 ohms. When the resistance of the clamp is increased such that it is more than ten times greater than the resistance of the tubing, the flow rate is insufficient to turn the paddle wheel.

- Because the final manometer tube pressure is at ground potential, or just very slightly higher, air enters the water stream, generating large bubbles downstream of the final T-piece. This retards the flow, causing pressure to back up at the final T-piece, and eventually the flow rate to speed up. As a consequence, the water level in the final manometer tube sometimes oscillates between heights of about 3 cm down to zero.

None of the less-than-satisfactory features are sufficiently detrimental as to ruin the general performance. Each is an interesting talking point:

- The ammeter cannot detect low currents.

- Wires have resistance, which cannot always be overlooked.

- The electrical analogue of the third detriment is an LC oscillation. The electrical analogue of inertia is inductance; and, because of the mass of flowing fluids, the system has this characteristic. The manometers store mechanical energy, which may relate to capacitance [1]. The oscillation at the tail-end of the circuit results from the combined effects of the resistance, inductance and capacitance built into the system.

Acknowledgement

Useful discussions were held with Jim Campbell (Lesmahagow HS) and Professor Miles Padgett (Department of Physics & Astronomy, University of Glasgow). Feymann's 'Lectures in Physics' has information on mechanical analogues of electrical properties.

Table 1 - Parts list for electric circuit model

Item	Supplier	Cat. No.	Cost (£)
Flow indicator, ¼″	Cole Palmer [2]	A-06297-05	10.79
Screw clamp x 3		A-06833-10	11.33
Keck clamp, 10 mm x 12		BH-06835-07	38.12
T-connectors, ¼″ ID tubing, x 10		A-30610-30	8.06
PVC Bubble Tubing ¼″ ID, 50 ft		A-95805-01	27.33
Coupling, Male, Hosebarb, ¼″ ID(valved panel connector)		A-06361-71	10.25
Hose Barb, in-line, ¼″		A-06361-51	5.28
Tray, 46 x 34 cm	Local		
Box, plastic, 53 x 34 x 15 cm			
Battery tank, 23 x 11 x 29 cm			
Submersible pump, 12 V	Opitec [3]	224.091	6.48
Hand-cranked generator	PASCO [4]	EM-8090	106.00

[1] Then again, the inverse of capacitance (1/C) is the electrical analogue of stiffness. Water is an incompressible fluid and would seem to have this property.
[2] Cole-Parmer, Hanwell, London W7 2QA; Tel: 020 8574 7556; Web: www.coleparmer.co.uk
[3] Opitec: 7 West Road, Woolston, Southampton, SO19 9AH; Tel: 023 80 44 69 91; Web: www.opitec.co.uk
[4] Feedback, Crowborough, East Sussex TN6 2QR; Tel: 01892 653322; Web: www.fbk.com

Security of radioactive holdings

Introduction

How safe are your sources? Generally they are looked after with great care. Yet, disturbingly, two instances have come to light in the past year of the disappearance of a school's radioactivity cabinet with its entire stock of sources. One occurred during a school closure; the other in the middle of a rebuilding programme – the story was told in a recent issue. They highlight the vulnerability of radioactive materials during irregular working operations. Whereas the security record during normal working procedures has been very good, the chance that things will go wrong increases ever so greatly during school reconstructions or closures.

A new report *Security of radioactive holdings* has been placed on the Members/ Downloads of the SSERC website. Please study it. It will also be on the *Radiological Protection* section of the new *SSERC SafetyNet CD*. Evidence reviewed in the report includes eight instances of the loss of radioactive material and the findings from school audits.

From incidents and audits, there is evidence of simple safety measures not being followed, and some staff failing to recognize that materials being held are radioactive. (Figures 1, 2 and 3 show examples of unmarked cloud-chamber sources. We have found these sources being kept wrongly with their instruments in insecure storage. They should be kept in the radioactivity cabinet.) There seems to be no supervision or monitoring by council officials in some councils. These councils need look at what happens in schools, helping where it is needed. Moreover the security of materials during school reconstruction work must be carefully managed.

Security: the critical points

- All radioactive materials must be kept in secure storage in a locked steel cabinet fastened to the fabric of the building or fixed furnishings.

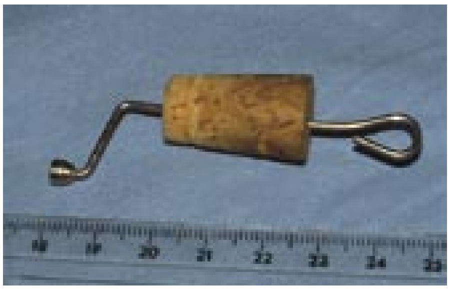

Figure 1 - Griffin diffusion cloud-chamber source. There is radium-based radioluminescent paint on the bell-end of the source holder.

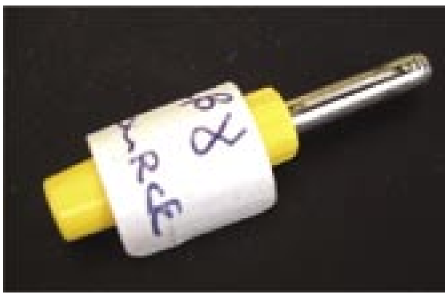

Figure 2 - Irwin diffusion cloud-chamber source. This is the worst example we have met with of an unmarked source. Irwin had drilled into the tip of a 4 mm plug and filled the hole with what we think is a radium-based paint.