instilling of detailed factual information and a greater emphasis on what Calder (1967) calls 'the analysis of complex systems'. This means attacking real-life problems with a combination of concepts taken from subjects which we have traditionally taught as separate entities. It will become more important in schools, as it already is in universities, to be able to formulate problems with precision than to be able to solve them in complete detail; more important to understand the capabilities and limitations of specialist fields of study than to be an expert in any one of them. The computers will attend to the details for us.

In conclusion: the next generation

There is a technical problem of communication concerned with ensuring that the message is received; there is a human problem concerned with ensuring that it is understood. One of the important messages from the microelectronics revolution is that we need intelligent machines and we must learn to accept them and work with them.

Many people have, understandably, serious misgivings about having to work with intelligent machines—robots and computers. They fear that the effects will be dehumanising. On the contrary, it is the *unintelligent* machines which bore and degrade the people who have to work with them.

We are, as teachers, more concerned with the next generation than we are with our own. There is a severe test ahead of us. If we take the ideas I have outlined too seriously, we may not survive. But if we cannot persuade the children to take them seriously enough, *they* may not survive.

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Further reading

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The Mpemba effect

The Mpemba effect—warm water freezes faster than cool—was first described in this magazine ten years ago in an article entitled 'Cool' by E B Mpemba and D G Osborne (Phys. Educ. 1969 4 *172-5). The article stimulated interest amongst teachers, pupils and the general public, and we have taken this opportunity of marking the decade by reprinting the original article below. In the following article, 'Mind on ice', D G Osborne suggests some possible explanations and poses a complementary problem. There then follows a report by M Freeman a London sixth former, of an A-level project on the phenomenon.*

Cool?

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Reprinted from Phys. Educ. 1969 4 *172-5.*

My name is Erasto B Mpemba, and I am going to tell you about my discovery, which was due to misusing a refrigerator. All of you know that it is advisable not to put hot things in a refrigerator, for you somehow shock it; and it will not last long.

In 1963, when I was in form 3 in Magamba Secondary School, Tanzania, I used to make ice-cream. The boys at the school do this by boiling milk, mixing it with sugar and putting it into the freezing chamber in the refrigerator, after it has first cooled nearly to room temperature. A lot of boys make it and there is a rush to get space in the refrigerator.

One day after buying milk from the local women, I started boiling it. Another boy, who had bought some milk for making ice-cream, ran to the refrigerator when he saw me boiling up milk and quickly mixed his milk with sugar and poured it into the ice-tray without boiling it, so that he may not miss his chance. Knowing that if I waited for the boiled milk to cool before placing it in the refrigerator I would lose the last available ice-tray, I decided to risk ruin to the refrigerator on that day by putting hot milk into it. The other boy and I went back an hour and a half later and found that my tray of milk had frozen into ice-cream while his was still only a thick liquid, not yet frozen.

I asked my physics teacher why it happened like that, with the milk that was hot freezing first, and the answer he gave me was that 'You were confused; that cannot happen'. Then I believed his answer.

In my next holidays I met a friend of mine who works as a cook in Tanga town. He used to make and sell ice-cream, for it is very hot in Tanga. (He told me that sometimes he made twenty shillings profit a day by selling ice-creams only.) I asked him how long it took to prepare them, and he replied 'I just boil milk with sugar and then add pineapple squash and put the mixture into the refrigerator while hot and the ice-creams are ready in a short time'. 'Who gave you that idea of putting hot liquids into the refrigerator?' I asked him. 'I was told by my brother, who has been making ice-creams for the past five years, that it works quicker that way'. Then I remembered that incident which happened when I was making ice-creams. From another young man who also sells ice-creams in Tanga I got the same answer, that if you use hot milk you get your ice-creams to freeze more quickly. But I did not bother to try to repeat the making of ice-cream by using both hot and cold milk.

After passing my O-level examination, I was chosen to go to Mkwawa High School in Iringa. The first topics we dealt with were on heat. One day, as our teacher taught us about Newton's law of cooling, I asked him 'Please, sir, why is it that when you put both hot milk and cold milk into a refrigerator at the same time, the hot milk freezes first?'. The teacher replied 'I do not think so, Mpemba'. I continued 'It is true, sir, I have done it myself' and he said 'The answer I can give is that you were confused'. I kept on arguing, and the final answer he gave me was 'Well, all I can say is that is Mpemba's physics and not the universal physics'. From then onwards if I failed in a problem by making a mistake in looking up the logarithms this teacher used to say 'That is Mpemba's mathematics'.

And the whole class adopted this, and anytime I did something wrong they used to say to me 'That is Mpemba's . . .', whatever the thing was.

Then one afternoon I found the biology laboratory open, and there was no teacher. I took two 50 cm^3 beakers; one I filled with cold water from the tap and the other with hot water from a boiler and I quickly put them in the freezing chamber of the laboratory refrigerator. After one hour I found that not all the water had been changed into ice, but that there was more ice in the beaker which had hot water to start with than in the other. This was not really conclusive. So, I planned to try it again when I had the chance.

When Dr Osborne visited our school we were allowed to ask him some questions, mainly in physics. I asked 'If you take two similar containers with equal volumes of water, one at 35 °C and the other at 100 °C, and put them into a refrigerator, the one that started at 100 °C freezes first. Why?'. He first smiled and asked me to repeat the question. After I repeated it he said 'Is it true, have you done it?'. I said 'Yes'. Then he said 'I do not know, but I promise to try this experiment when I am back in Dar es Salaam'. Next day my classmates in form six were saying to me that I had shamed them by asking that question and that my aim was to ask a question which Dr Osborne would not be able to answer. Some said to me 'But Mpemba did you understand your chapter on Newton's law of cooling?'. I told them 'Theory differs from practical'. Some said 'We do not wonder, for that was Mpemba's physics'.

I asked the head of the kitchen staff at school to let me use a refrigerator for this experiment. She gave me the use of one whole refrigerator for a week. First I did the experiment by myself, because I was afraid that if it failed anyone else would tell the whole school that I was just stupid on that day when I asked the question. But my results were the same. The following day I took three boys with me from among those who had scorned my question and performed the experiment. We found that ice started to form first from the hot milk.

These three boys laughed very much and started telling the others that I was right, but that they could hardly believe it. Some said it was impossible. I told the head of the physics department in my school that the experiment had worked, he then said 'It should not. I will have a go at it this afternoon'. But later he found the same result.

An answer? by D G Osborne

The headmaster of Mkwawa High School invited me to speak to the students on 'Physics and national development'. I spoke for half an hour but questions lasted for a further hour. There were questions of personal concern about entering the university, loaded questions about the remote possibility of relating parts of the school syllabus to national development and questions that showed a considerable breadth of reading, including one on gravitational collapse. One student raised a laugh from his colleagues with a question I remember as 'If you take two beakers with equal volumes of water, one at 35 °C and the other at 100 °C, and put them into a refrigerator, the one that started at 100 °C freezes first. Why?'.

It seemed an unlikely happening, but the student insisted that he was sure of the facts. I confess that I thought he was mistaken but fortunately remembered the need to encourage students to develop questioning

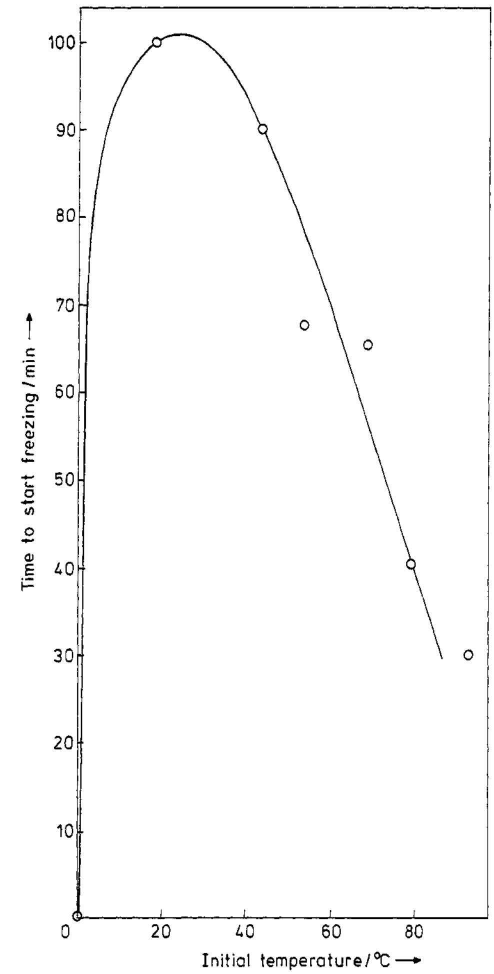

Figure 1 Plot of time for water to start freezing against initial temperature of water

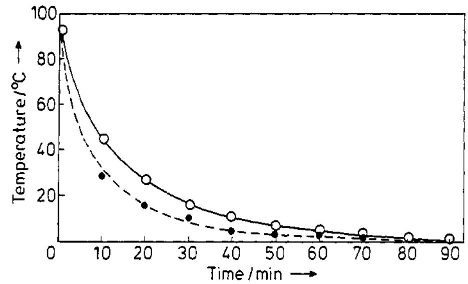

Figure 2 Rate of cooling of water from an initial temperature of 93 °C. Upper curve indicates temperature near the surface; lower curve temperature near the bottom

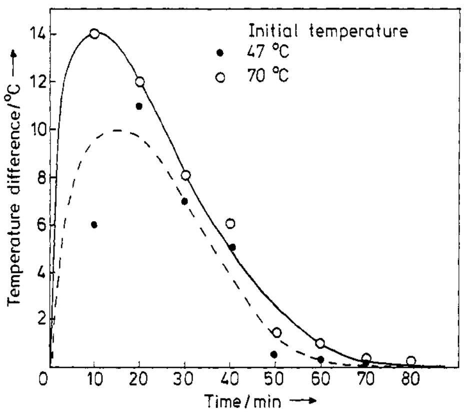

Figure 3 Difference between temperatures near the surface and the bottom of two samples, plotted against time

and critical attitudes. No question should be ridiculed. In this case there was an added reason for caution, for everyday events are seldom as simple as they seem and it is dangerous to pass a superficial judgment on what can and cannot be. I said that the facts as they were given surprised me because they appeared to contradict the physics I knew. But I added that it was possible that the rate of cooling might be affected by some factor I had not considered. I promised I would put the claim to the test of experiment and encouraged my questioner to repeat the experiment himself.

At the University College in Dar es Salaam I asked a young technician to test the facts. The technician reported that the water that started hot did indeed freeze first and added in a moment of unscientific enthusiasm 'But we'll keep on repeating the experiment until we get the right result'. Further tests have vindicated the student's claim and we think they point the way to an explanation.

The facts described by this Tanzanian student may be familiar to many, though I had not heard of them before and have found as yet no reference to them. He visited the University College in Dar es Salaam a few weeks after asking me the question and wrote an account of how he had met the problem. His account starts this article, written in his own words but with a few omissions. It points to the danger of an authoritarian physics and is recorded in the hope that it will be of interest and encouragement to others who teach physics.

But what of the problem itself? Because of the element of surprise in this simple observation we based a project for second-year university students upon it. In a series of experiments, test systems of 70 cm^3 of water in 100 cm^3 pyrex beakers of approximately 4.5 cm diameter were frozen in the icebox of a domestic refrigerator. The beakers were supported on a sheet of polystyrene foam, providing thermal insulation. It was observed that:

(1) If two systems are cooled, the water that starts hotter may freeze first.

(2) The graph of 'time to start freezing' against initial temperature has the shape drawn, approximately, in figure 1.

(3) An oil film on the water surface delayed freezing for several hours, showing that without this film most of the heat lost escapes from the top surface.

(4) Only small changes in volume occur due to evaporation; the latent heat of vaporisation cannot account for more than 30% of the cooling and cannot alone be responsible for the rapid freezing of systems with high initial temperatures.

(5) A temperature gradient is established in the liquid.

(6) Dissolved air was eliminated as a factor by using recently boiled water for the trials starting at all temperatures.

Curves for temperature against time for cooling from 93 °C are shown in figure 2 with curve S showing temperature near the top surface of the liquid and curve B temperature near the bottom. For a lower initial temperature the separation between the curves is less. Figure 3 shows the temperature difference between positions near the top and bottom of the water samples, plotted against time, for initial cooling from temperatures of 70 and 47 °C. The times to start freezing shown in figures 1–3 are not comparable as conditions in the refrigerator were different in the three cases. In practice the relatively rapid cooling of a system that starts hot may be accelerated if it establishes better thermal contact with the case of the freezer cabinet through melting the layer of ice and frost on which it rests. This factor was eliminated from our tests by resting the cooling beakers on a good thermal insulator.

Cooling occurs mainly from the top surface. The rate of cooling depends on the surface temperature of the liquid and not its mean body temperature. Convection within the liquid maintains a 'hot top' (presumably while above 4 °C) and the rate of loss of heat for an initially hot system can be greater than for an initially cooler system even when they have cooled to the same mean body temperature. A trained physicist may be surprised by the reported quicker freezing of the hotter liquid because it has to pass through intermediate temperatures before freezing. However, the systems are not described adequately by a single temperature for they have temperature gradients that depend upon their previous history.

The suggested explanation in terms of convection establishing a temperature gradient and maintaining rapid heat loss from the top surface must be considered a tentative one. The experiments attempted were relatively crude and several factors could influence cooling rates. More sophisticated experiments are needed to provide a more certain answer to the question.

Informal discussions about this observation have provoked reports of a similar phenomenon where the explanation of top surface cooling is difficult to apply. According to these reports hot water pipes freeze more quickly than cold water pipes during frosty weather. It is not appropriate to test the validity of this claim in Tanzania.

Acknowledgments

We are indebted to the headmaster and staff of Mkwawa High School for generating this enquiry and to the students and staff of the Department of Physics, University College, Dar es Salaam, for encouragement and advice. We would welcome any information about references to this problem in the scientific and technical literature.

Queries in physics

Q454 (from *QIP*47)
The velocity of sound in a gas is given by $(\gamma p/\rho)^{1/2}$, the γ being required because expansions and contractions are adiabatic and γ, besides being c_p/c_v, is also the ratio of adiabatic to isothermal elasticities. γ must be a property of solids and liquids as well as gases, so surely expressions like $(E/\rho)^{1/2}$ should either specify adiabatic E, or include γ? Possibly for solids and liquids γ is very close to 1?

Q455
Recent advertising draws attention to an oscilloscope in which the spot traverses the screen at up to two thirds the speed of light *in vacuo*. Is there a theoretical maximum spot speed?

The above items were selected from *QIP*, a thrice-yearly broadsheet. It is available on subscription at a rate of £2 per annum from the editor, Mr W H Jarvis, Salewheel House, Ribchester, Preston PR3 3XU. All correspondence concerning this feature should be addressed to Mr Jarvis.