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A RANDOMWALK THROUGH FRACTAL DIMENSIONS

Synopsis of a presentation to the American Association of Physics Teachers, Ontario Section, Annual Meeting, Sudbury, Ontario, June 22, 1987.

By Brian H. Kaye, Professor of Physics, Laurentian University, Sudbury, Ontario P3E 2C6.

In 1982 I was privileged to address you at your annual meeting in London, Ontario. At that time I discussed how classical physics such as properties of matter had tended to be overlooked in our teaching of physics in favour of some of the apparently more glamorous solid-state nuclear physics systems etc. At the end of the lecture I was approached to ask if some of the material on the applied physics of instruments I presented was available in written form. The answer was no but the question stimulated me to plan a book to be entitled "Delightful Instruments" and "Exciting Moments in Applied Science". The idea being that I would describe some of the more modern instruments that embody exciting aspects of physics. I am afraid that I have only produced one chapter of the book which I have titled "Harmonious Rocks and Infinite Coastlines" in which I discuss some rather novel applications of Fourier Analysis and fractal geometry. I have brought a copy of this chapter along for you to inspect. The reason the project has not developed further is that my involvement with fractal dimensions has escalated to the point where at times I wonder what I did before I began exploring the infinite patterns of fractal geometry. [Fractal geometry studies rugged systems such as fragmented rocks and extends the concepts of dimensional description of a system to include a fractional addition to the classical dimension of a system to describe its space filling abilities.] When I was asked to address you again this year I thought it would be a good opportunity to introduce fractal geometry to a wider audience. The problem with a subject such as fractal geometry is that it is so different from the traditional way of thinking that it takes a mental effort to swing around to gain a fresh perspective of geometry, dimensional analysis and its exciting concepts. My book on fractal goemetry entitled "A Randomwalk Through Fractal Dimensions", to be published by VCH Publishers of Germany early next year, is almost finished. The rather odd title comes from the fact that one soon discovers that randomwalk modelling and fractal geometry are intimately linked. I have expressed this fact to my students by saying that if you scratch a fractal set you will probably find a randomwalk underneath. Fractal goemetry is finding many applications in applied science and its elegant simplicity if one can get past its strangeness, means that it can be used even at the pre university level. Over the last year a guest student in the gifted mathematics program of Lasalle High School here in Sudbury has spent one day a week exploring fractal dimensions and I am pleased to say that already some of the data she generated will be incorporated in my book. I can assure you that although high school students find fractal geometry intriguing and stimulating they have semantic problems and mental concept problems to start with. We have so conditioned them with calculus that they find it strange to discover curves that have no differential function and they have come to expect that there is one goemetry and one algebra handed down by God to Moses on Mount Sinai. They need to be re-educated that there are more geometries and more algebras than they have ever dreamed of.

My teaching of fractal geometry at the introductory level has reinforced my impression that one of the reasons that the majority of students in science programs dislike physics is because they are not used to symbolic logic and find it difficult to use a Latin/Greek base vocabulary that is remote from their everyday experience. The mastery of symbolic logic requires a different part of the brain to that used to process verbal information and unfortunately western education bypasses symbolic pattern recognition leaving Chinese students trained in pictographic writing (a form of symbolic logic) to walk away with our mathematic prizes). The students who survive our physics programs go on to teach others in the same way that they were taught and so we have bred a generation of students who wallow in acquired symbolic logic but who are almost illiterate when it comes to describing the poetry of physics and the wonder of the universe. Like the dinosaur we have specialized ourselves almost out of existence since the mainstream of general students pass us by and the bread and butter of physics departments is becoming rigid service courses for engineers. If we are to ever have students clamouring to get into physics courses we must teach students to love words and to collect them and use them as precious things. We must also explain to them the beauty and elegance of symbolic logic not as an obscure language necessary for the initiated but as elegant pictorial summaries of fascinating facts. We could have students from a broad range of abilities enjoying physics if we would only stop wallowing in symbolic logic and start to teach the human history of physics as an exciting story of discovery of the universe. I know that after I managed to graduate in physics I became so fascinated with the intellectual elegance of the subject that I am sure that the first year I taught the University physics course at Laurentian using Halliday and Resnick it was as abstract as Picasso's pictures. It probably left many students wondering about its connection with reality in the same way that many of us react to the abstract paintings of Picasso. I intend over the next few years to specialize in developing physics courses for non science majors and to this end I have started work on several projects. Some of the early stages of these projects are available for you to inspect at the close of this lecture.

First of all, to enrich the vocabulary levels of the students, I have started to work on a book that is called "Word People of Science". A chapter from this book called from "Euclid to Mandelbrot" has been especially prepared to enable students in the gifted program to explore fractal mathematics. I have also started to work on a book called "Face Powder and Quantum Physics". I am finding that the work I have done with the mixing of powders is in fact quantum physics only one deals with glass beads instead of Plank's constant. I am convinced that quantum physics is only difficult because everybody said it should be and that one can sneak into the subject by the back door by looking at the applied physics of mixing. The problem with an invitation such as this to speak to such an assembly of physics teachers is that time is so limited - and so, having introduced these area concepts and projects, I will now show you some diagrams from Euclid to Mandelbrot then I will show you how randomwalk modelling can be carried out on an average lab computer to simulate the gaussian distribution and a fractal front of interest to oil recovery scientists. Hopefully these illustrations will encourage you to follow up these topics when the written material I am preparing becomes available in published form.

Display Summary

1. Sample chapter from Delightful Instruments and Exciting Moments entitled Harmonious Rocks and Infinite Coastlines an Exploration of Fourier Analysis and Fractal Geometry fo Characterizing Rock Fragments. Copies available for student and personal use at the cost of copying and postage $8.50.

2. From Euclid to Mandelbrot. A semantic survival kit for those who would like to begin to explore fractal geometry.

   [Draft copies available for student and personal use at the cost of copying and postage $11.00. Combined order for 1 & 2, $15.00.]

3. Face Powder and Quantum Physics. An introduction to the quantized universe of applied sciences uses experience from powder mixing.

4. Efficient Symbolic Communication In the Work Place. A discussion of how the eye-brain system processes symbols.

5. Excerpts from Chapter 4 and 5 of "A Randomwalk Through Fractal Dimensions" by Brian H. Kaye, to be published by VCH Publishers, Weinheim, Germany.

References

1. B. B. Mandelbrot, Fractal Geometry of Nature, W. Freeman, San Francisco, 1983.

2. Art Matrix, P.O. Box 880, Ithaca, N.Y., 14851, U.S.A. (Fractal postcards and computer programs).

SCARBOROUGH - JUNE 1988

The tenth annual conference will be held at the University of Toronto, Scarborough Campus, from Sunday June 26 to Tuesday June 28.

Talks in the planning stages include new findings in high-temperature superconductivity and Supernova Shelton 1987A. As usual, contributed papers, "My favorite demonstrations", and posters will be welcome. So take part in your conference!

See you at Scarborough in June!

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THE DEMONSTRATION CORNER

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This is the second appearance of this column, which has been prompted by the great popularity of the demonstration sessions at our annual conference. Submissions describing demonstrations will be gladly received by the editor.

The Belt-Hanger

One category of good physics demonstrations involves the "disorientation" or "disequilibrium" of students. The demonstrations in this category cannot be explained by most students, and thus serve to disorient the students and put them into a state of disequilibrium from which they wish desperately to escape.

Such demonstrations pique the students' curiosity and gain their attention. Some students have been known to throw up their hands and say that these demonstrations can be explained only by magic. At this point, the students are like putty in the teacher's hands — they are eager to learn the real explanation.

The belt-hanger described below is a nice disorientation demonstration, and it is cheap to make and easy to use.

Fig. 1 shows a belt-hanger in (full-size) cross-section, and can be used as a pattern from which to make your own belt-hanger. It can be made from a variety of materials: wood, metal, thick cardboard, etc. The ideal thickness is about 1 cm (the aluminum one I have currently is 9 mm thick).

Once the belt-hanger has been made, position it on the end of a fingertip as shown in Fig. 2. It is unstable in this position and falls to the floor.

Now remove your belt or have a student remove his/her belt (teachers who are "hams" can embellish this step in various ways — music, clapping, etc.). A firm leather belt with a reasonably large buckle is best. Fasten the belt buckle so that the belt forms a closed loop, and place the belt on the hanger (on your fingertip) as shown in Fig. 3, with the buckle at the bottom of the belt.

Instead of the hanger and belt falling to the floor, the entire system is quite stable! For added effect, you can place the hanger (and belt) on the edge of a table or on the top of a door frame instead of on your fingertip.

Students are surprised that the hanger is unstable by itself, but stable when the belt is hung on it.

HOW IT WORKS — **If an object (which is free to rotate) is to be in stable equilibrium, the centre of mass (CM) of the object must be below the pivot point.**

When the hanger alone is placed on a fingertip, it is impossible for the CM to be positioned below the pivot point without the hanger sliding from the finger and falling. (The pivot point is just the contact point between the hanger and the finger.)

When the belt is on the hanger, the CM of the system (hanger + belt) is now positioned somewhere in the middle of the loop formed by the belt, and it is "easy" for the CM to be under the pivot point, with stable equilibrium being the result.

WHY DO IT? — **First, it engages the students' minds in attempting to explain a physical phenomenon.** Second, although centre of mass is not a topic which is taught in detail at the high school level, it is useful to point out to students that the acceleration a in Newton's Second Law ($\Sigma F = ma$) is the acceleration of the CM of the object, and it is then nice to have at least one demonstration related to CM.

At the university level, the topics of CM, torque, stable and unstable equilibria are considered in detail, and CM demonstrations related to equilibrium are very useful.

WANT MORE CM DEMONSTRATIONS? — refer to an article "Centre of Mass Revisited" in *The Physics Teacher*, January 1983.

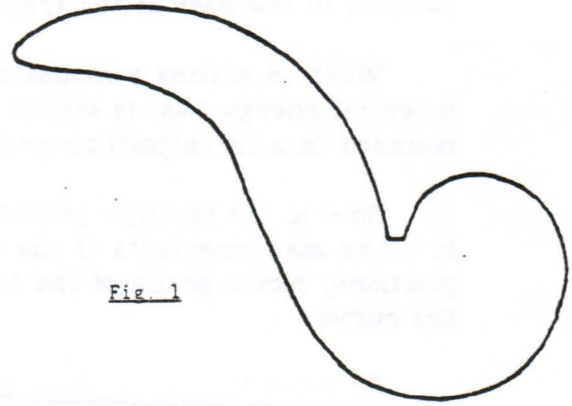


Fig. 1

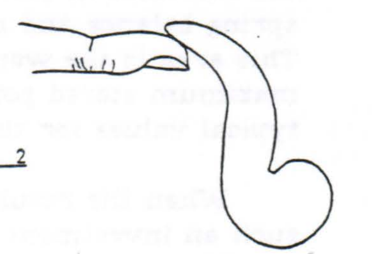


Fig. 2

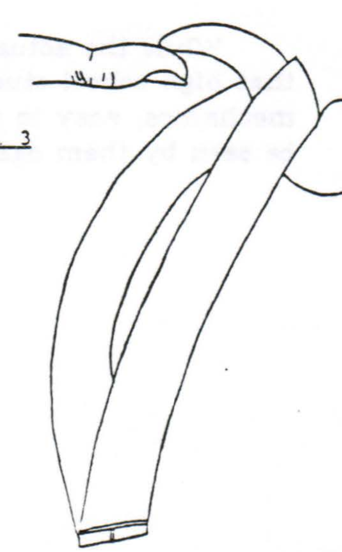


Fig. 3

Setting a Mousetrap

In recent years mousetrap mobile contests have been very popular in high school science. This contest encourages thinking unlike the analytical thinking that students do so much of the time in solving physics problems. Students are left with an open ended problem of invention: Devise a home-made "car" that is powered solely by the energy in the spring of a mousetrap. Usually these cars are tested, the car moving the greatest distance winning the contest.

To make the mousetrap's spring the source of energy for a home-made car offers students a lot of physics, fun, and advantages. Here's a device providing a good example of Hooke's law. If the force of the spring is measured tangent to the arc swept out by the trap then the force is directly proportional to the angle of the trap. Yet if the force is measured parallel to the base of the trap it's a good example of a nonlinear force.

Work in setting a mousetrap can be measured. The maximum potential energy that is stored in its spring can be calculated from the area bounded in a force/position graph.

How is the spring's potential energy calculated? The basic procedure is to make measurements of the force parallel the base of the trap at various positions, plot a graph of the force versus position, and find the area under the curve.

To avoid the dot product in work, students measure the force parallel to the base. If this force is measured at enough positions along the base then a graphical exercise of finding the area under the curve bounded by the extremes in position of the trap is reasonably accurate. Only a 20 N spring balance and a ruler or protractor are needed to get useful data. This area is the work done in setting the trap and so is equal to the maximum stored potential energy in the trap. For the mousetrap we use, typical values for this energy are 0.65 J ±0.05J.

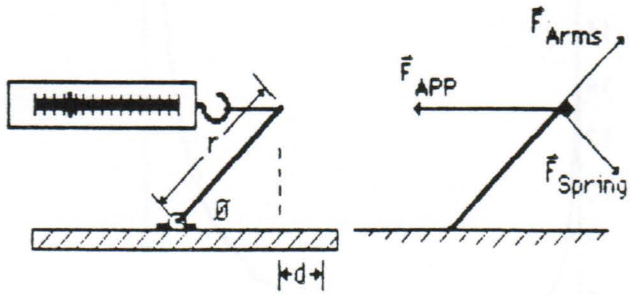
When the results of this exercise are completed most students feel that such an investment of effort requires that they build the best mousemobile possible with their trap.

While the actual materials and measuring devices are crude, the ideas that high school students grapple with here are all from elementary mechanics, easy to understand, and fun to apply. The concepts will likely be seen by them again if they deal with other machines or engines.

The Energy in a Mousetrap

Aim: To find the potential energy that can be contained in the spring of a "standard" mousetrap.

Diagram:



Procedure: Each laboratory pair of students will be given a mousetrap. This mousetrap is to be retained by the group after the end of the exercise. There is some danger in this exercise so keep your fingers out of the reach of the trap as you attempt to set it!

In order to find the energy in the trap, the total amount of work done on the trap by setting it will be calculated from a graph of force versus distance. This work done on the trap is the same as the total potential energy contained in the trap's spring when completely set.

a) Measure the length of the spring action of the trap, "r", in metres. Express "d" as a function of "r".
b) Attach a wire to the trap so that a 20. N spring balance can be used or pulling. Calibrate the 20. N spring balance before starting. Be sure that when measuring the force applied you have no friction between moving parts in the spring balance.
c) Clamp the trap down to your desk and have a protactor ready on one side to measure angles.
d) Displace the trap 20° and measure the applied force, holding the balance horizontally. Record the information in the table below. Repeat this procedure to complete the table.
e) Plot a graph of force versus distance and find the area under the curve of the graph from initial position of the trap to its final position. In finding this area some estimating needs to be done.

Data:

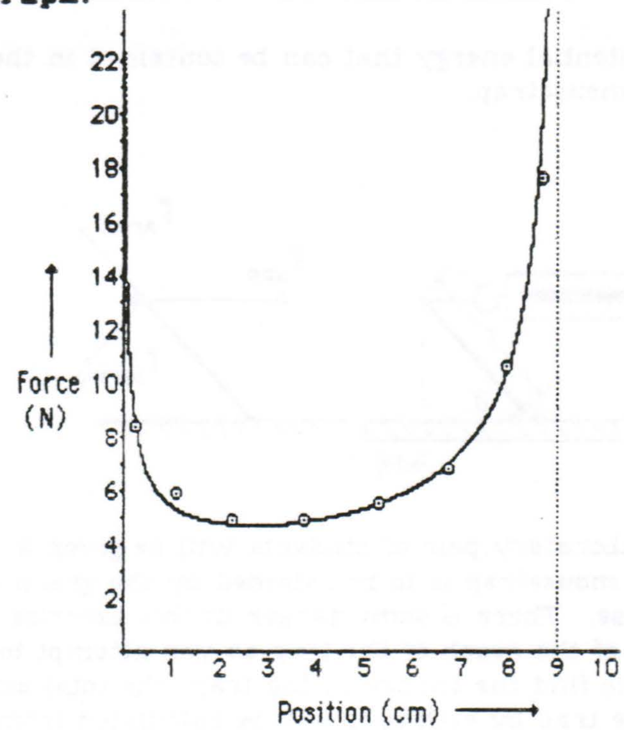
a) r = ______ m   d = ______________________

d)

Angle	d (m)	F (N)
20°		
40°		
60°		
80°		
100°		
120°		
140°		
160°		

The area under the "F vs d" graph is ______ J.

Expected Graph:



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Membership Form

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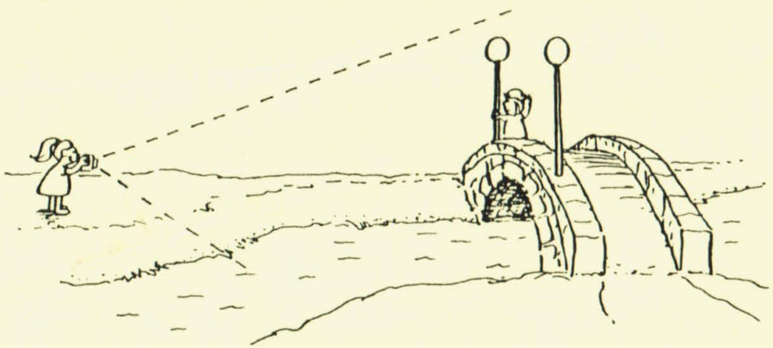
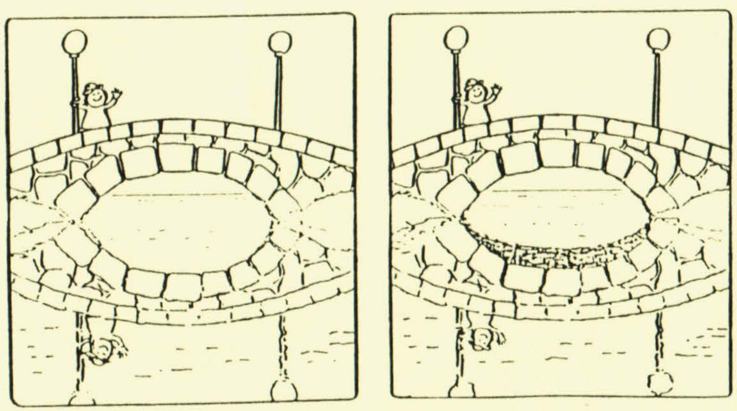
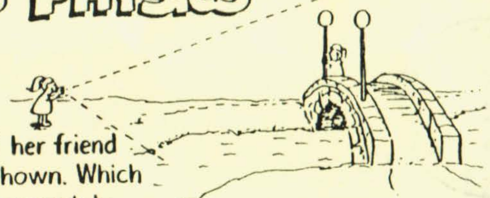
Figuring Physics



She takes a photograph of her friend standing on the bridge as shown. Which of the two sketches more accurately shows the photograph of the bridge and its reflection?



Figuring Physics



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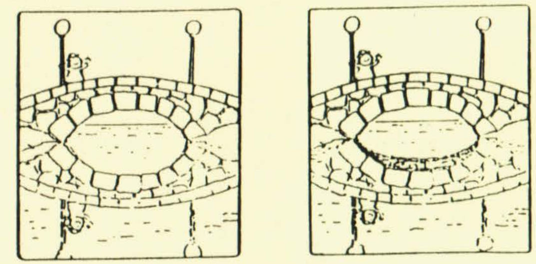

Answer:

The sketch on the right shows a more accurate reflection of the bridge. The reflected view is not simply an inversion of the scene above, as some people think, but is the scene as viewed from a lower position -- from the water surface. The reflected view of the bridge is the view the girl would see if her head were upside down at the water surface where the light is reflected. Hence the reflected view shows the underside of the bridge.