Notes and Discussions

drift or instability in \( f \), and their ultimate accuracy depends on the calibration of the oscillator or other source of reference frequency.

We have found a modification of the methods proposed by Maxwell and Dillman particularly simple and convenient for measuring \( f \). This is to use a solar cell mounted on the wall to the side of the rotating mirror and normal to the reflected light beam to monitor the light from the mirror. The light beam strikes the solar cell twice during each revolution of the mirror since the mirror is silvered on both sides. The solar cell output is fed to an ac amplifier and then to a counter. The number of counts per second is then equal to \( 2f \). This technique is especially useful in that a helium–neon laser can be used as the light source for the experiment since the solar cell is particularly sensitive in the red region of the spectrum.

Light from a Spectra-Physics Model 134 laser (2.5 mW) was passed through a beam splitter to the rotating mirror and then to a Cenco No. 81095 silicon solar cell, shunted by a 470-ohm resistor to improve its frequency response. The output of the solar cell was fed into an ac amplifier with a gain of 100 (e.g., Hewlett–Packard Model 466A) that was then able to provide voltage pulses of sufficient height to drive a counter (Monsanto Model 100A) at all frequencies. At the highest frequencies (2 to 1000 cps) the input to the counter was about 100 mV.

This counting technique was checked using a General Radio type 1531-AB strobatoc to make sure that no counts were being lost at the higher rotational frequencies, and that no spurious counts were being generated by stray light or 60-cps pickup. Agreement was better than 1% for frequencies of rotation between 200 and 500 cps. (A simple check on the accuracy of the counter is to turn on the fluorescent lights in the room and see if the counter records 120 cps.)

Since the frequency of rotation is not the limiting factor on the accuracy with which \( c \) is determined in the Foucault method, most of the above methods are capable of determining the frequency of rotation to sufficient accuracy. The last method has the advantage, however, of enabling a large number of frequency readings to be taken both rapidly and directly from the face of the counter. This makes it possible for the student to observe drifts or fluctuations in frequency at the same time he is measuring the beam displacement. The drift can be as much as 2%–3% in a few minutes. This method also enables the student to record as many as 20 readings of \( f \) very rapidly and to use these readings to analyze both the statistical and systematic errors in \( f \). In addition this technique has the peripheral advantage of introducing the student to lasers, solar cells, and counters, which play such an important role in modern physics research.


Variations on a Famous White-Light Experiment of Isaac Newton

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In one of his best-known experiments, Isaac Newton dispensed a beam of light into its rainbowlike color spectrum by means of a prism. Then he ran the dispersed light through a second prism oriented so as to bend the light beam oppositely to the way it was bent by the first prism. Thus the various colors were recombined and gave white light again.

It occurred to me that this experiment might be done using two diffraction gratings instead of two prisms. It turns out to be very easy. The result is spectacular.1

All you need is two cheap replica transmission gratings (one pair for each student).2 You also need an ordinary frosted or (preferably) “soft white” light bulb to provide the white light, and a darkened room. The detector is your eye. You hold one grating in your left hand about 6 or 8 in. from your eye and oriented so that the colors are dispersed vertically. Using your left hand to block out the direct light from the bulb to your eye, displace your left hand vertically upwards until you see the first-order color spectrum coming from the aperture of the grating to your eye. Now with your right hand hold the second grating close in front of your eye and oriented parallel to the first grating. If you look towards the place in space where the real light bulb would appear (if you could see through your left hand) you will see there a lovely virtual white light bulb. Optics works: It’s astounding!

The alignment of the two gratings is not critical; they may be held freely in your hands. By slight shifting vertically of the grating held in the left hand (the one farthest from your eye) you may allow less than the full color spectrum diffraeted at that grating to be incident on the second grating. Thus you may make the virtual bulb appear red or blue rather than white. But by slight adjustment of your left hand you may insure that the bulb will appear white. The experiment is best done in a very dark room or at night since the virtual bulb is not very bright. In a room not completely dark the experiment will still work if you provide a darker background than your hand by paperclipping.
the first grating to the edge of a dark-covered book or piece of dark cardboard. The book is used in place of your hand to block out the direct light from the bulb, and to provide a dark background for viewing the virtual light bulb.

Once you have seen the bulb you can put other objects near the bulb so as to be illuminated by it; for example, a crumpled up wad of aluminum foil. The whole scene is recreated in its original colors by the second grating. A dim sharp image floats there like a ghost in space, just where the real object would be if your hand were transparent. It's ravishing!

\[1\] I have not heard of this demonstration before, but I have not searched the literature.

\[2\] I used the replica transmission gratings available at 25¢ each (or 10¢ each in lots of 100) from Edmund Scientific Co., 300 Eisco Bldg., Barrington, N. J. 08007.

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**Problem of the Three**

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Suppose a time machine transported you back to the year 1000 AD. What relevant technology could you reconstruct? Could you make a slide rule?

Slide rules, only a decade ago an engineer's badge of distinction, are now so common they hang for sale at some supermarket check-out counters. How they work is almost universal knowledge. But who understands why they work? understands why on an intuitive level? The why becomes apparent by making one. Mark off 1, 2, 4, 8, 16, 32, 64 at equal intervals on a paper strip. Slit as illustrated in Fig. 1, and you have a crude slide rule.

But is it a real slide rule? Someone will quickly answer it is a base 2 slide rule; a real commercial slide rule is base e. Often this objection is countered by another claiming a real commercial slide rule is base 10. The question reveals the real basis for understanding a slide rule is not communicated in mathematics text book explanations regardless of how logically rigorous the text may be.

Inspecting a commercial slide rule reveals separation of the numbers 1, 2, 4, 8 as well as 1, 3, 9 or even 1, e, e^2, e^3 are, and must be, equal. That is what makes it work! The point is that a logarithmic scale, like a slide rule, has no specific base. Any number will do. It is just a geometric progression. A realistic objection to the 1, 2, 4, 8, etc., slide rule is that it is too coarse for practical use. There is no obvious way to refine the 1, 2, 4, 8 rule. That is the problem of the three. There is no way to tell where between two and four it should be placed, and there are similar problems with all primes.

Generations of inquisitive high school students (myself among them) have by themselves discovered all the foregoing before their sophomore year. Yet there, at the problem of the three, they are stymied. Of course, they could appeal to a table of logarithms, but that would be cheating (there were no log tables in 1000 AD). Might as well buy a slide rule (I did) and be done with it. This is almost tragic because success is already within reach, though it may never be known. (It took me 14 years to see the light.)

The key is any number will do, because a geometric logarithmic scale has no specific base. Even a number like 1.1, so choose it. As shown in Fig. 2 this results in a rather fine scale. The integers 2, 3, 4, 5, etc., can be located with a bit of interpolation. But if this is not good enough go to a finer scale like 1.01, and so on. There is no limit on how accurate the slide rule can be made, if you have enough patience. The goal is reached.

This refinement brings understanding to a stage verging on rediscovery of the celebrated number e. That number, it will be recalled, was originally uncovered by trying to compound a vanishingly small rate of interest instantaneously.

Let 1.1 represent one dollar, 1.0, the principal, and one dime, 0.1, the interest. Then \((1.1)^n\) represents total return, principal plus accrued interest, after \(n\) compoundings.

Suppose we found a bank so generous it would pay 100% interest per year. Then our endowment would double each year and after \(n\) years be \((1+1)^n\). But suppose the bank was to compound semiannually;

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**Fig. 1.** Slit the strip along the dotted line. The lower section demonstrates the slide rule in use. It is multiplying (or dividing) by four.