corder with floating inputs (Hewlett–Packard 7035B), a bias battery, a shorting switch, and a capacitor. These components are connected as shown in Fig. 1. The size of capacitor required depends on the output of the constant current source and the response time of the recorder. For sweep times of around 10 sec using the specific equipment models listed above, an electrolytic capacitor of 100–500 μF at 50 W V dc is satisfactory. A variable voltage limit on the constant current source, while not required, makes calibration of the voltage scale on the recorder simple, and prevents possible damage due to excessive voltage. Note that the output of the constant current source as well as the x-axis input to the recorder must be floating with respect to ground.[4]

A typical trace resulting from the apparatus is shown in Fig. 2. By careful calibration of the recorder voltage scale, values for current maxima and minima can be read from the trace to three significant figures. This precision allows students to apply statistics to the differences in maxima and minima voltages to determine a random error in their estimate of the excitation potential of Hg.

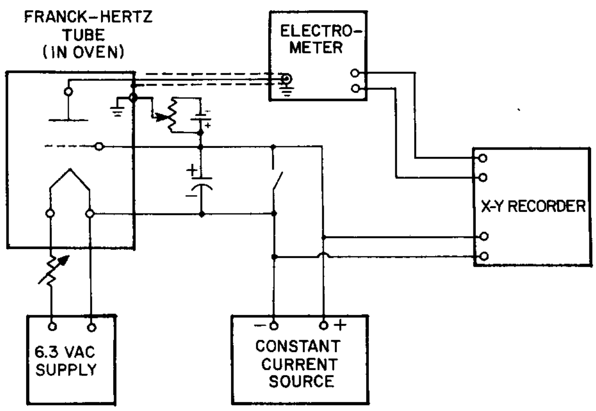

Fig. 1. Connection of Franck–Hertz apparatus for X–Y-recorder readout. Note that all power supplies and the X–Y recorder are not grounded and must have floating chassis.

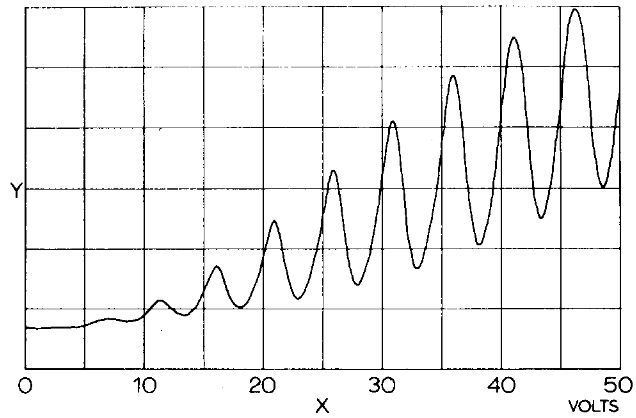

Fig. 2. Typical X–Y-recorder trace from Franck–Hertz experiment using apparatus of Fig. 1.

The same technique can obviously be used to obtain graphs of current–voltage characteristics for a wide range of electronic devices (provided the voltage limit is made to correspond to the device ratings). Thus such a setup, while requiring expensive equipment, can be used efficiently by sharing it with a beginning electronics laboratory, for example, allowing students to have characteristic curves on standard graph paper—the major advantage of the X–Y-recorder approach.

[1]W. J. Caley, Jr., Am. J. Phys. **40,** 1877 (1972).
[2]R. E. Adelberger and K. F. Kinsey, Am. J. Phys. **40,** 349 (1972).
[3]There are a variety of instruments which could be substituted for the models given in parentheses, with the exception of the Franck–Hertz tube and oven.
[4]If a constant current supply is not available, one can usually be approximated with available voltage sources and solid state components. Strict linearity of the sweep is not necessary; however, the maximum sweep speed is determined by the recorder response time while the minimum sweep speed is limited by the oven temperature stability, so that the sweep rate needs to be maintained within these bounds (about 3–10 V/sec).

Weightlessness in free fall

James B. Cashatt
Michael S. Harmon
L. Steve Kluttz
Andrew S. Pitts
D. Craig Saunders
David M. Tesh
Ronald B. Wilkins
Suzanne M. Lea
Science Department
Davidson County Community College
Lexington, North Carolina 27292
(Received 30 April 1973; revised 14 January 1974)

Students in a physical science class usually greet with skepticism the claim that a spring balance with a weight attached, located in a freely-falling reference frame, will read zero. Since our institution lacks an elevator suitable for the usual demonstration of the dependence of weight on acceleration, it was decided to photograph a freely-falling spring balance with a weight attached.

The first-year physics laboratory as taught at our institution allows some time for students to work on experiments chosen by them. It was suggested to a group that this project would be suitable for a laboratory experiment. This group did all of the planning, construction, and photography. They spent approximately three 3-h laboratory periods, in addition to some of their own time, on the project.

A weight of approximately 500 g was attached with masking tape to a standard laboratory spring balance (Ohaus, Science Kit). The balance was in turn attached by an eyelet to Cartesian axes measuring 12 in. × 12 in. × 18 in., constructed of 2 in. × 2 in. delta pine, glued with epoxy. The center of mass was adjusted so that the apparatus hung vertically by using extra length on the z axis and by inserting 165 g of lead into appropriate spots.

The apparatus, supported by nylon fishing line, was released by a spring-operated plunger. It was guided during its descent by three vertical nylon lines passing through eyelets attached to the axes. Since care was taken to stop oscillations of the apparatus before releasing it, friction from these lines is negligible. To prevent damage to the apparatus, it was caught at the bottom of its descent by one of the experimenters.

The photographs were made with Ektapan ASA 100 film in a 4 × 5 view camera set at *f*/22 with an open shutter. Three 0.004-sec. speed lights were triggered when the bottom of the weight cut the beam of an 0.1-mW He–Ne laser aimed at a phototransistor. (A diagram of the triggering circuit is available on request.) To obtain higher contrast, the film was developed for 14 min at 68°F with Kodak D76 developer (1:1 dilution).

Photographs were made of the apparatus at rest and after it had fallen distances of 1.0 m, 1.5 m, and 2.0 m. Because the lights were of relatively long duration and not exactly synchronized, there is some blurring; however, the scale readings are clearly visible. (As expected, the scale reads zero while the apparatus is falling.) Copies of the photographs are available from Dr. Lea upon request.

Radio recombination lines, quantum numbers and Rydberg's constant

Jay M. Pasachoff
Hopkins Observatory
Williams College
Williamstown, Massachusetts 01267
(Received 23 September 1974)

In hot clouds in interstellar space, electrons recombining with hydrogen, helium and carbon ions give off series of spectral lines corresponding to high values of n. Using a notation where $Ly\alpha$, $Ly\beta$ and $Ly\gamma$ are 1α, 1β, 1γ, and the Balmer series is 2α, 2β, 2γ, etc,[1] astronomers have been using radio telescopes for the last half-dozen years to observe lines like 109α, 272α and 256β. Simple calculator or computer calculations that extend n from low to high values, elucidate the formula very nicely.

The frequency of a transition is

$$\nu = Z^2 Rc\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right) = A\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right).$$

The optical wavelength of the Balmer line $H\alpha$ is about 6563 Å, and the constant can be readily computed from this with a desk calculator

$$A = \frac{c}{\lambda}\,\frac{1}{(3^{-2} - 2^{-2})}$$
$$= \frac{2.994 \times 10^{10}\ \mathrm{cm/sec} \times 10^{8}\ \text{Å}/\mathrm{cm}}{6563\,\text{Å}\,(3^{-2} - 2^{-2})}$$
$$= 3.2846 \times 10^{15}\ \mathrm{sec}^{-1}.$$

Then a desk calculator or computer[2] can be readily programmed to give values or tables of such lines as hydrogen 272α

$$\nu = A\left(\frac{1}{272^2} - \frac{1}{273^2}\right) = 324.65\ \mathrm{MHz}$$

which is about 92 cm in wavelength.

The difference of this value from the actual value of 324.9915 MHz shows the effect of rounding the optical $H\alpha$ wavelength and illustrates how measurements of physical parameters can often be made more precisely with radio spectroscopy.

Desk calculators using reverse Polish notation, such as the HP−35, may be used in an interesting exercise to compute these values. For example, ν can be calculated without intermediate storage by keystroking: A, enter, 272, enter, ×, $1/x$, 273, enter, ×, $1/x$, − , × ; whereas A was similarly calculated by keystroking: 2.994, E EX, 10, enter, E EX, 8, ×, 6563, ÷ , 2, enter, ×, $1/x$, 3, enter, ×, $1/x$, − , ÷ .

With calculators using forward notation, ν can be calculated, with somewhat greater attention to parentheses, by keystroking: 272, x^2, $1/x$, − , 273, x^2, $1/x$, = , × , A, =.[3]

For carbon, the frequencies are increased over those for hydrogen by the ratio of the Rydberg constants

$$\frac{R_C}{R_H} = \frac{1 - m_e/m_C}{1 - m_e/m_H} = \frac{1 - (1800 \times 12)^{-1}}{1 - (1800)^{-1}} = 1.0005$$

The 272α line is thus shifted by 0.16 MHz.

Through such calculations students become familiar with effects of changes in n and of nuclear mass. They can then be referred to papers in the current literature, including many in the *Astrophysical Journal*, to see applications of these results.

[1] Patrick Palmer and B. Zuckerman, Nature (Lond.) **209**, 1118 (1966).
[2] A. E. Lilley and Patrick Palmer, Astrophys. J. Suppl. Ser. **16**, 143 (1968).
[3] I am indebted to Daniel F. Muzyka for this remark.