A student experiment on optical bistability

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A hybrid system that consists of an oscilloscope and a photodiode is used to demonstrate optical bistability. The details of the experimental setup and its graphical solution will be presented.

I. INTRODUCTION

Optical bistability is a rapidly expanding field of current research because of its potential application to all-optical logic and because of the interesting phenomena it encompasses.1 An optical system that possesses two different steady-state transmission states for the same input intensity is said to be optically bistable.

Thus a system having the transmission curve of Fig. 1 is said to be bistable between \( I_1 \) and \( I_1' \). Such a system is clearly nonlinear, i.e., \( I_1' \) is not just a multiplicative constant times \( I_1 \). In fact, if \( I_1 \) is between \( I_1 \) and \( I_1' \), knowing \( I_1 \) does not reveal \( I_1' \). Nonlinearity alone is not sufficient to assure bistability. It is feedback that permits the nonlinear transmission to be multivalued, i.e., bistable.

An undergraduate experiment on optical bistability has been reported using a PLZT modulator as the nonlinear switch.2 Here, we would like to present an interesting experiment in which an oscilloscope and a photodiode are used to demonstrate optical bistability.

II. EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 2. The hybrid optically bistable system consists of a student oscilloscope (SCOPE-1) and a photodiode (DET) facing the screen of the oscilloscope. The signal detected by the photodiode is amplified by a preamplifier (AMP) whose circuit is shown in Fig. 3. The amplified signal is then feedback to the \( Y \) input of the SCOPE-1.

The optical bistability can be observed by varying the intensity or the horizontal position of the light spot on the screen. In order to monitor the optical hysteresis curve of Fig. 1, a signal generator (OSC) with sine output is connected to the \( X \) or \( Z \) input of SCOPE-1 to vary the horizontal position or the intensity of the light spot on the screen. For convenience, another oscilloscope (SCOPE-2) is used to observe the optical switching. Under proper conditions we can observe a hysteresis curve similar to Fig. 1; here, the horizontal coordinate could be the horizontal position or intensity of the spot, and the vertical coordinate is the signal detected by the photodiode. In order to have a clean

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result, one should use an oscilloscope with the graticule removed or defocus the spot if the graticule cannot be removed (many new oscilloscopes have an internal graticule).

Typical observed optical hysteresis curves are shown in Figs. 4(a) and (b). In Fig. 4(a) the intensity of the light spot on the screen is varied while its horizontal position is varied in Fig. 4(b). There are two bistable regions in Fig. 4(b); this is because our system is symmetric with respect to the photodiode. When the system is in the bistable region, a brief shining of a flashlight on the screen of the SCOPE-1 will switch the output from low state to up state. Obstructing the path between the light spot and the photodiode will restore the system to the low state. Also, by varying the vertical sensitivity and the vertical position or intensity of the light spot, one may observe the clipper, limiter, and differential gain modes of this system.

III. THEORY

In order to analyze the optical bistability, we have to know the signal detected by photodiode before feedback is on. This can be obtained by varying the position of the light spot and tracing out the photodiode response. Suppose the projection position of the photodiode onto the oscilloscope screen is the origin, then the photodiode output $I_T$ varies with the spot position as

\[
I_T = a I_f \exp - (x^2 + y^2)/b^2
\]  
(1)

approximately, where $(x, y)$ is the position of the light spot, $a$ and $b$ are constants, and $I_f$ is the intensity of the light spot. This relation is clearly nonlinear. After feedback, then the height of the light spot will be changed by

\[
y - y_0 = acI_f \exp - (x^2 + y^2)/b^2.
\]  
(2)

Here, $c$ is another constant, and $y_0$ is the height of the light spot before feedback.

Let us study the case of varying spot intensity first. For convenience of analysis, set $x = 0$; then

\[
(y - y_0)/acI_f = \exp(-y^2/b^2).
\]  
(3)

Then the value of $y$ can be graphically determined as shown in Fig. 5. In Fig. 5, both the right- and left-hand sides of Eq.
(3) are plotted together, and the intersection gives the value of \( y \). As the intensity of the spot, i.e., \( I_y \) increases, the slope of the straight line decreases. Figure 4 shows two straight lines labeled UP and DOWN that correspond to the range of spot intensities for which there are three interactions of a line with the Gaussian curve. Therefore, we have an S-shaped curve between \( I_y \) and \( I_z \) (determined by the straight lines cabled UP and DOWN in Fig. 5, respectively), and the section with negative slope can be proved unstable; therefore, we have a hysteresis curve as shown in Fig. 1.

Similarly, one can analyze the case of varying the horizontal position of the light spot. Now, we have

\[
(y - y_0) \exp(x^2/b_z^2) = acI_y \exp(-y^2/b_z^2),
\]

and the value of \( y \) can be graphically determined as in Eq. (3) using Fig. 5. Now, the slope of the straight line is proportional to \( \exp(x^2/b_z^2) \) which decreases as \( |x| \) decreases, and Eq. (4) is an even function of \( x \); therefore, we have the hysteresis curve shown in Fig. 4(b).

IV. CONCLUSION

The phenomenon of optical bistability is an interesting dynamical process having potential for all-optical data processing and having interesting phase transition properties. A simple and interesting optical bistable system is set up using an ordinary student oscilloscope and a photodiode. This system is used to demonstrate the requirements of optical bistability. The same system can also be used to study optical chaos by introducing a delay in the feedback.

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Electron conversion for selected nuclides

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An analysis is made of the spectra resulting from the process of internal conversion to measure the inner-shell binding energy of certain nuclides. Use is made of the \( K/L \) ratio of the internal conversion coefficients to predict spin and parity changes in the electromagnetic transitions involved. Such an analysis can quite easily be introduced into an undergraduate nuclear laboratory program.

I. INTRODUCTION

When an atom is in an excited state, having had an electron removed from an inner shell by whatever means, it may return to a state of lower energy by the emission of an x-ray photon. Alternatively the reorganization of the atom may occur without the emission of electromagnetic radiation. In this case the energy is communicated to another electron of the same atom which is then ejected from the atom. The latter process is called the Auger effect\(^1\) in recognition of the work of P. Auger who discovered it in 1925.

When a nucleus is in an excited state, whether it be as a result of the emission of an alpha particle, of a beta particle, or as a consequence of a nuclear reaction or decay, that excited state will normally decay to a state of lower energy or to the ground state by emission of a gamma ray photon or by the ejection of an electron from one of the atomic orbits by a process discovered in 1924 by Hahn and Meitner\(^2,3\) called internal electron conversion. It was soon realized that the proper quantum mechanical description of the process does not correspond to the emission of a gamma quantum by the nucleus and its subsequent reabsorption by the bound atomic electrons though some internal photoelectric effect. The probability of such an event occurring is negligibly small. It is rather an interaction between the radiation field near the nucleus and the atomic electrons.

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\(^4\) See Ref. 1, Chap. 6, and the references therein.