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PoLARIZATION OF A HELIUM-NEON LASER

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Low-power helium-neon (HeNe) lasers with power outputs of less than one milliwatt are commonplace in introductory physics laboratories. The end mirrors that form the resonant cavity are sealed to the laser tube body. For this reason these lasers are known as integral mirror lasers. Because of the cylindrical symmetry of the cavity, there is no preferred direction of polarization and the emerging laser beam is said to be randomly polarized.

After a brief warm-up, a HeNe laser emits a (nearly) steady light that may be put to a variety of uses. If, however, the light from the laser is passed through a linear polarizer, the resulting intensity is no longer constant. Instead the transmitted intensity changes noticeably with time, especially during the first hour or so of operation from a cold start.

It occurred to me that measuring the intensity of the laser light passed by a linear polarizer would make an interesting experiment for my second-year physics students. Although the necessary measurements change too rapidly to be made by reading a light meter, they can be made quite easily with the aid of a photocell monitored by a computer. As it happened, the experiment was better than I expected for it generated real excitement in the students who had no preconceived idea of what they were looking for. Not only were they fascinated by their observations, but they were led in a natural way to discussions about what was happening and to further experiments.

Polarization Effects

We began by examining the output from a Uniphase 155sl laser. The total light output was detected with a photocell monitored with a computer. The intensity was essentially constant with time over an interval of 30 minutes after switching on the laser from a cold start. Beam intensity measurements with a digital light meter were 0.60 mW with fluctuations of less than 0.01 mW.

We then placed a linear polarizer in the path between the laser and the photocell; the transmitted light was measured under conditions that were otherwise identical to those made without the polarizer. The intensity was seen to oscillate in time with a gradually increasing period (Fig. 1). After approximately one hour the quasiperiodic behavior ceased and no pattern was discernible. The students then went on to measure the light output over intervals as long as 19 hours. They also found that switching off the laser for even a few minutes was sufficient to initiate the oscillations all over again.

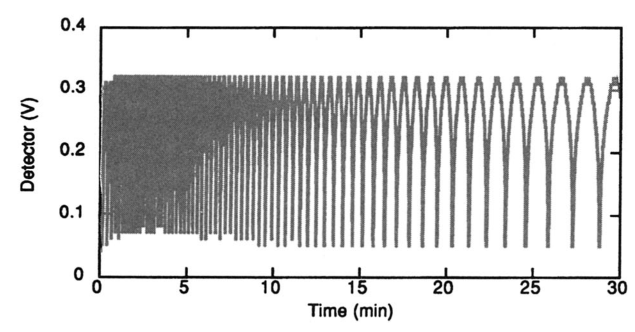

Fig. 1. Beam intensity of a HeNe laser after passing through a linear polarizer.

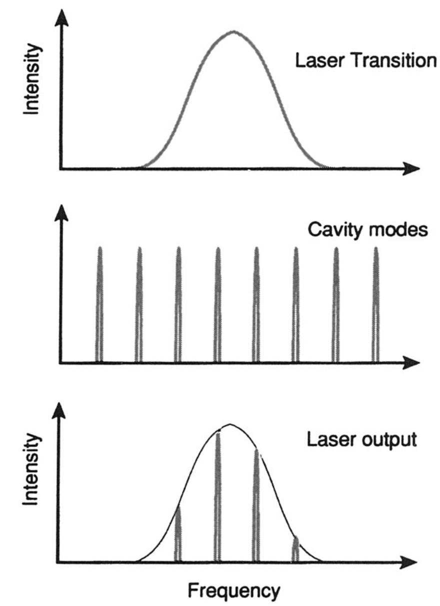

Fig. 2. The width of the atomic emission is greater than the separation between the cavity modes. Laser lines result from the overlap of the transition with the cavity modes. Spacing between adjacent cavity modes decreases as the laser tube heats up and expands because their separation is inversely proportional to the distance between the end mirrors.

Seven different lasers were examined: two Metrologic ML810 lasers and two Uniphase 155sl lasers, all manufactured in 1994, and three Spectra Physics 155A lasers manufactured in 1982. The Metrologic and Uniphase lasers had very similar behavior. The older Spectra Physics lasers also showed the quasiperiodic behavior, but their waveforms were much more complex.

Explanation of the Behavior

The time-dependent polarization of the integral mirror HeNe lasers is a consequence of several factors: the width of the lasing transition line, the resonant frequencies of the cavity formed by the mirrors, and thermal expansion of the laser tube.[1,2] In HeNe lasers, the sharp resonance frequencies of the cavity are so closely spaced that several of them exist within the span of the transition line.[3] As a result, the laser light is not just a single frequency but contains several very closely spaced frequencies (Fig. 2). The output beam of the laser consists of two linearly polarized components. Adjacent modes are orthogonally polarized while alternately spaced modes correspond to the same polarization.

During warm-up, the laser tube expands causing a slight narrowing in the spacing between the cavity modes. The resulting behavior is as if the cavity modes are swept through the transition line, causing the relative intensities of the contributions from the different modes to change and therefore causing a shift in the polarization components in the output laser beam.

Examining Orthogonal Polarizations

We also examined the intensities of two orthogonal polarization directions simultaneously. To do so, a nominal 50-50 cube beam splitter divided the beam and directed the two parts to separate photocells, which were monitored by the computer (Fig. 3). As with all cube beam splitters, the exact amount of light in the emerging beams depends on both wavelength and polarization of the incident light. With the cube in place and without polarizers in place the emerging light showed intensity fluctuations with time, indicating that the beam splitter was partially polarizing the light sent in either direction.

We then placed polarizers between the beam splitter and the photodetectors. The polarizer in the transmitted beam was aligned with its transmission axis horizontal and polarizer in the deflected beam was aligned with its transmission axis vertical. With this arrangement each detector could sense only the light polarized in the direction set by the polarizer. When the intensity of light in one polarization direction increased, the intensity in the other direction decreased (Fig. 4). The two intensity profiles are complementary. Consequently, the total intensity, which is the sum of the intensities of the two orthogonal polarizations, is constant as observed earlier.

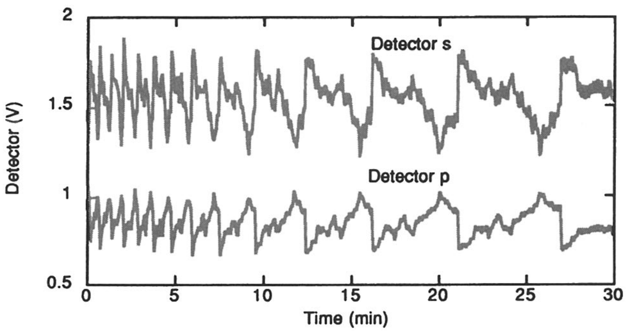

Fig. 4. Intensity in two orthogonal polarization directions of light from a Spectra Physics 155A laser. Polarizations correspond to the setup of Fig. 3. Polarizer at *p* is horizontally aligned and that at *s* is vertically aligned. Magnitudes of the two waveforms are not scaled the same because the detectors were not identical.

Further Experiments

The experiment described here leads naturally to several other interesting areas of exploration for the students. One of these is an examination of the behavior of a diode laser[4] for both stability and polarization. Another is to examine the effect of the beam splitter by measuring the ratio of transmitted to deflected intensities of the beam splitter as a function of the initial state of polarization.

Yet another important question that arises naturally from this experiment is the effect of the rate of data-gathering. What the students will observe during the first few minutes of operation of the laser will depend critically on their choice of data rate. If they want to collect data over an extended interval of time, then the rate will be necessarily slower than if they only look for a short time. The patterns seen under these two conditions may well be different owing to the effect of aliasing associated with a sampling time that is too slow to follow the oscillation of the signal that is being sampled. Thus a detailed study of the effects of sampling frequency is a natural follow-up to the laser experiment.

Instrumentation

The detectors for our measurements consisted of inexpensive photocells[5] connected to the voltage input of a Vernier Universal Lab Interface (ULI) that was controlled by a Macintosh SE computer. Because the output of the photocell was low, we boosted it with an amplifier built from an LF351 operational amplifier powered by a bipolar power supply. The amplifier circuit was configured as a current to voltage converter by means of the feedback resistor (Fig. 5). In this way the computer detected a voltage output from the amplifier that was proportional to the current generated in the photocell by the inci-

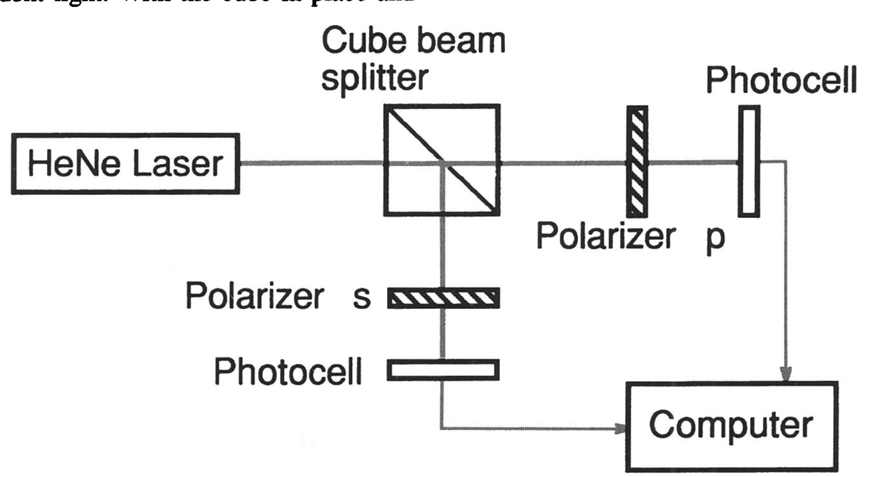

Fig. 3. Alignment of laser with beam splitter, polarizers, and photocells. Arrangement allows simultaneous detection of two orthogonal polarizations.

dent laser light. The linearity of the detector was confirmed by measuring the light intensity passed by a set of calibrated neutral density filters.

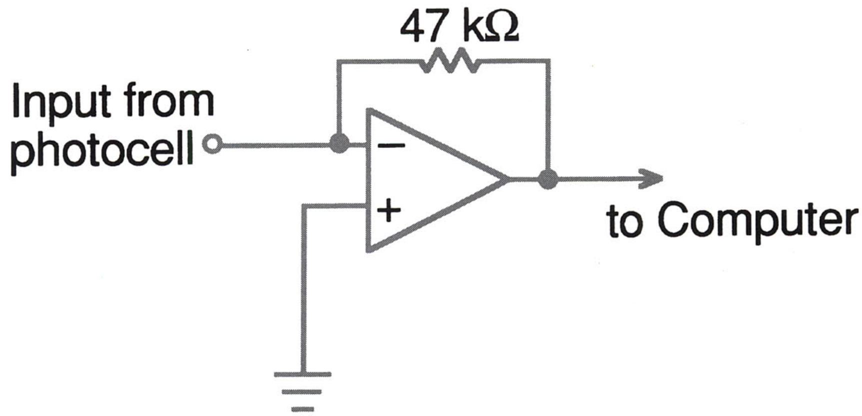

Fig. 5. Operational amplifier circuit has output voltage proportional to input current generated by the photocell.

Acknowledgments

I would like to thank the students of my Physics 308 class for their contributions to this work. Particular credit goes to Daniel Kris Finkenstadt who assembled much of the apparatus.

References

1. J.A. Duardo, S.C. Wang, and W. Hug, in *Polarized Light*, edited by W.L. Hyde and R.M.A. Azzam, *Proc. SPIE* **88**, 34 (1976).
2. R. Balhorn, H. Kinzman, and F. Lebowsky, *Appl. Opt.* **11**, 742 (1972).
3. D.C. O'Shea, W.R. Callen, and W.T. Rhodes, *Introduction to Lasers and Their Applications* (Addison-Wesley, Reading, MA, 1977), pp. 89–92. The separation between adjacent cavity mode frequencies is $c/2L$, where c is the speed of light and L is the distance between the end mirrors.
4. Diode laser pointers such as the Metrologic ML211 are available for about \$50. Individual laser diodes and drive circuits can be obtained from Meredith Instruments at 602-934-9387.
5. The photocell was part of a solar power kit, Radio Shack #277-1201, that cost about \$10.

Trick of the Trade

A Very Quick and Very Cheap Velocity-of-Sound Lab

Most lab manuals for introductory physics include a velocity-of-sound lab that utilizes tuning forks in conjunction with a resonance-tube apparatus. The water level in a vertical, graduated glass tube is adjusted by means of a movable reservoir. As the height of the water column is gradually increased, resonance points are observed. The distance between adjacent resonance positions is also the distance between adjacent antinodes, and thus equals ½ wavelength. It is a fairly tedious and somewhat subjective procedure; students must try to judge when the tone is the loudest.

I've discovered that an interesting, simple, very quick, and surprisingly accurate result may be obtained using the cardboard tube from a paper-towel roll as "apparatus." The tube is struck on a hard, blunt surface (students often suggest one of their colleague's heads) near a microphone connected to a frequency meter. Results cited here were obtained using the Vernier Microphone/Amplifier, ULI, and *Sound* software. When used in the Fast Fourier Transform (FFT) mode, a frequency peak at 554 Hz invariably results when the tube is struck.

Several lab manuals[1] employ a method similar to that first described, but observing only one antinode, and taking the length of the closed tube to be ¼ wavelength. Using this method, 0.4 times the inside diameter of the tube must be added to the length of the tube to obtain the "effective length," which "accounts for the small amount of air just above the tube which also vibrates." (I don't know the derivation of the 0.4. Perhaps it is empirical.)

The length of the cardboard tube from a paper-towel roll is 28.0 cm, and its average diameter is 3.78 cm. Since this is an open tube, I added 0.4 times this at both ends, obtaining an "effective length" of 31.0 cm, which represents ½ wavelength. Using this wavelength and the 554-Hz resonant frequency yields 343 m/s at 20°C!

Reference

1. Paul Robinson, *Laboratory Manual with Computer Applications—Beiser Physics*, 5th ed. (Addison-Wesley, Reading, MA, 1991), p. 126.

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