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Methodological Notes

GAS LASER—LECTURE DEMONSTRATIONS OF ITS OPERATION AND ITS USE IN PHYSICS TEACHING LABORATORIES

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THE study of the operating principles of lasers has already been firmly entrenched in the programs of general physics courses, and should obviously be supplemented by practical lecture demonstrations. It is therefore essential to describe a certain minimum number of experiments which should accompany a lecture explaining the operation of a laser. D. Dutton, M. Parker Givens, and R. E. Hopkins have described in Amer. J. Phys. 32, 355 (1964) lecture demonstrations in which predominant use is made of the high directivity of laser radiation. We shall discuss here other aspects of laser operation.

Teaching experience has shown that even a low-power cw gas laser (several mW) is sufficient for a illustrative explanation of the operating principles of optical generators of directed coherent radiation to a large audience. The gas laser has in this respect even certain advantages over a pulsed crystal laser, for in the latter, the instructive factor in the demonstration is actually the important effect of a powerful light flash rather than the laser operating details.

The point is that the small dimensions of the operating crystal of a laser (relative to demonstration requirements), which is furthermore enclosed in an illuminator, do not lend themselves to explanations of the construction details to a large audience. Of course, the lucidity of the production of population inversion of the electron levels in chromium atoms by optical pumping argues in favor of demonstrating a crystal pulsed laser, too. Finally, it must be noted that aa gas laser is easier to construct than a crystal laser, and is safer in use, this being an essential requirement that must be satisfied by any teaching device, especially when used in practical demonstrations.

1. LECTURE DEMONSTRATIONS WITH A GAS LASER

We describe here only the principal demonstrations that illustrate the operating principle of a laser and its features as a light source. We have specifically in mind a helium-neon laser which operates, as is well known, with a resonator.

1) An important aspect in explaining the operation of this laser is a demonstration of the role of its mirror resonator. It is necessary to show that the discharge tube and the resonator mirrors form jointly, under certain conditions, a self-excited generator of directed coherent radiation.

Under the conditions of a rigidly mounted gas laser, operating under fixed gas and electric conditions, it is, however, very easy to realize the required experiment. The gas laser together with the two semitransparent resonator mirrors radiates powerful light beams symmetrically, through both mirrors. It can be shown that when the section of the light beam between one of the ends of the discharge tube and one of the mirrors is blocked by an opaque body, the laser beams through both mirrors become extinguished. This operation corresponds to a decrease in the resonator Q and a resultant cessation of the laser oscillations.

This experiment illustrates clearly the difference between the operating conditions of a laser and that of an ordinary gas-discharge tube with an extended glowing positive column. It is obvious that the two glowing ends of an ordinary gas discharge tube are not interrelated, and that blocking one of the beams emerging from the tube does not affect the intensity of the other.

If one of the resonator mirrors of a home-made laser is not transparent, then an opaque shutter should be introduced between the end of the discharge tube and the opaque mirror, which again causes extinction of the laser beam passing through the semitransparent mirror. Modern factory-produced gas lasers are sometimes completely enclosed in a sealed jacket to protect the ends of the discharge tube and the resonator mirrors against dust. It is then necessary to remove this jacket for such a demonstration.

2) If the laser discharge tube is closed on both ends with plane-parallel glass plates inclined at the Brewster angle to the laser beam, then it is easy to demonstrate with the aid of a polaroid the linear polarization of the laser emission. It is also easy to explain its cause.

The expediency of so orienting the output glasses lies, as is well known, in the requirement that there be no reflection losses in the tube windows for radiation polarized in the plane of incidence. It is then impossible to generate radiation polarized in the plane perpendicular to the plane of incidence.

3) The natural directivity of the laser light beam can be readily demonstrated in the lecture hall without using any optical collimating systems. It is advanta-

geous to determine on the spot the diffraction broadening of the light beam under the experimental conditions.

4) The spectral decomposition of the gas-laser radiation can be readily realized with the aid of a prism or a diffraction grating. However, the most important experiment with the laser, from the spectroscopic point of view, is, of course, the proof of the small widths of the Ne 6,328 Å spectral line. This proof, of course, can be realized only with the aid of an interference experiment using for example, a Michelson interferometer. Here, however, we shall describe a simpler version of an interference experiment.

For such an experiment the setup is oriented to let the laser light beam propagate towards the audience. A lens with focal distance 10–15 cm is placed directly at the exit of the light beam from the resonator mirror. Behind the lens is located an opaque plane screen perpendicular to the axis of the lens and parallel to the rows of students in the auditorium. The white surface of the screen faces the listeners. In the center of the screen (on the lens axis) is a round hole 6–7 mm in diameter, which transmits the light beam converged by the lens. Farther on the axis of the light beam, approximately 1.5 meters behind the screen, is a plane-parallel glass disc approximately 20 mm thick and 70–80 mm in diameter.

The plane of the disc is parallel to the plane of the screen. In this case the light is reflected from both surfaces of the disc back to the laser and strikes the screen. This produces on the screen, around the hole, a system of intense, clear, and sharp annular interference fringes of equal slope. The diameter of the interference rings is approximately 15 cm under the conditions of this experiment.

The observed visibility $V = \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}$ of the interference fringes (let alone the luminosity E produced on the screen) cannot be realized with any other source of light, including one with a cadmium lamp.

The same setup can be used for a second variant of the interference experiment. Without using a lens or a screen, the laser beam is projected directly on the glass disc described above. It is then possible to reflect the light beams from both surfaces of the disc back to practically any corner of the auditorium. The reflection from the disc, projected on the walls or on the ceiling, is marked by sharp interference fringes. For an increase in the size of the reflection and the fringes, it is convenient to use oblique incidence of the light reflected from the disc onto a specially installed screen.

2. LABORATORY WORK WITH A GAS LASER

As one of the main problems of general physical laboratory experiments with a gas laser, we recommend the study of the fine structure of the spectral lines of light scattered by liquids and crystals[1].

As is well known, the spectral lines of light experiencing molecular scattering in liquids and in solids acquire a fine structure. The phenomenon, predicted separately and independently by L. I. Mandel'shtam and L. Brillouin, was experimentally observed long ago[2], but until recently its observation was possible only in very precise scientific experiments. The cause of the phenomenon, as interpreted by Mandel'shtam, is the modulation of the scattered light by the time-varying molecular-statistical fluctuations in the scattering medium. In Brillouin's interpretation, the phenomenon is due to the Doppler effect on Debye thermal waves. Thus, the phenomenon itself and both equivalent interpretations are rich in physical material and can serve as a very favorable object for laser applications. The final quantitative result of this investigation is the calculation, from the interference spectrograms, of the speed of sound in various media at a frequency $\sim 10^{10}$ cps. The use of interference spectroscopy in the experiment provides the students with splendid additional educational material.

The main difficulty in observing the effect is the low intensity of the scattered light and the very small frequency splitting of the spectral line. When an ordinary light source with a line spectrum is used, the width of the spectral lines is too larger to be able to demonstrate the splitting and to calculate the speed of sound from its value. The situation is radically different, however, when a laser light source is used. Spectrograms obtained by us[3] with the aid of a laser (Fig. 1) can be processed by the students without difficulty.

The experimental setup is shown in Fig. 2. Behind the exit mirror M_2 of the laser resonator is located an optical system for the study of the molecular scattering of light. A very thin (cross section ~ 0.5 mm^2) needle-like beam of exciting radiation ($\lambda = 6328$ Å) was produced with the aid of the objective O. Behind the crystal (or behind a cuvette with liquid) is placed a concave mirror M_1, which reflects the light back to the crystal and the laser. By precisely adjusting the position of the mirror M_1, we succeeded in combining the light beams which pass many times between this mirror and the laser output mirror M_2 into a single light beam coinciding with the primary beam. This yielded a four-fold gain in scattered-light intensity

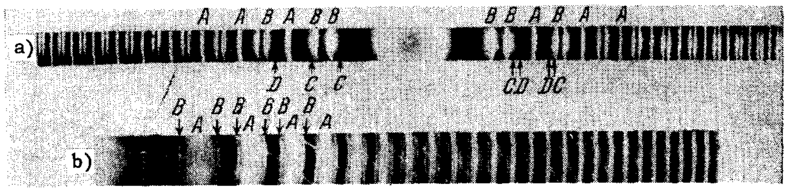

FIG. 1. Spectra of scattered light; a) quartz; b) NaCl; AA–exciting line, BB–the same line modulated with a longitudinal elastic wave; CC and DD–result of modulation with the aid of transverse elastic waves.

Crystal	Calculated Longitudinal elastic wave, m/sec			Transverse elastic wave, m/sec		
	Δλ, Å	Measured	Calculated	Δλ, Å	Measured	Calculated
NH_4Cl+Co	0.228 ±0,001	±4650 ±25	4430	0.117±0,001	2380±25	2110
NaCl	0.204 ±0.002	4450 ±50	4480			
KCl	0.169 ±0,003	3820 ±70	3830			

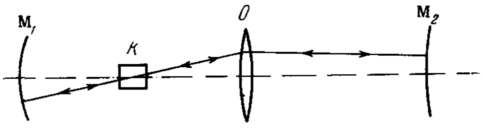

FIG. 2. Diagram of illumination of the crystal (aperture of light beam strongly exaggerated).

compared with single utilization of the primary laser beam in the crystal. Moreover, as demonstrated by a photoelectric indicator mounted against the opposite (non-working) window of the laser discharge tube, the output power of the laser increased somewhat under these conditions. The scattered light was observed at an angle of 90° to the primary light beam passing through M_2. The figure does not show the condenser for focusing the scattered light, and the remaining parts of the optical setup (see below).

The laser light passed along an edge of the cubic lattice of the crystal, and the scattered light was observed along another edge of the lattice.

The electric vector of the laser beam was linearly polarized perpendicular to the scattering plane and directed parallel to one of the edges of the crystal lattice of the cubic crystals. The scattered light was linearly polarized with a Nicol prism identically with the primary light beam in all cases, except for the observation of the scattering by transverse waves in $NH_4Cl + Co$ crystals. In the latter case the scattered light was polarized in the scattering plane with a Nicol prism. In the case of quartz, no Nicol prism was used when observing the scattered light. The spectral decomposition of the light scattered at an angle of 90° was by means of a Fabry-Perot interferometer (see Fig. 1). To illustrate the quality obtained, we present the spectrograms for NaCl and SiO_2. We note here that the quality of the spectrograms under the conditions of laser illumination was determined exclusively by the degree of perfection of the crystals available to us. The processing of the experimental results was by measuring the positions of the satellites of the Rayleigh line on the spectrogram, so as to exclude sighting on overexposed images of undisplaced spectral lines.

The results of the measurements of the satellite displacements (Δλ) and the speed of sound v obtained from them are listed in the table. In addition, the table lists the values of the speeds of sound calculated from the elastic constants of the crystals[4].

In conclusion we present some technical data concerning the installation employed. A laser with output power of approximately 5 mW was mounted on an optical bench (OSK-2). The spectral decomposition was by means of an IT-51-30 Fabry-Perot interferometer. The interference patterns were photographed with the camera of the ISP-51 spectrograph, with focal distance 270 mm. The exposure on panchromatic film for the case of crystals was from 50 minutes to two hours, but in the case of benzene the fine structure of the spectral lines of the scattered light was reliably observed with an eye piece located in the plane of the camera plate holder. The interference patterns were processed with an IZA-2 comparator using, for example, the method described in [5].

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Translated by J. G. Adashko