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THE DESIGN AND CONSTRUCTION OF A LASER METER FOR THE MEASUREMENT OF CW IRRADIANCE AT 623.8 NANOMETERS

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U.S. Department of Health, Education, and Welfare
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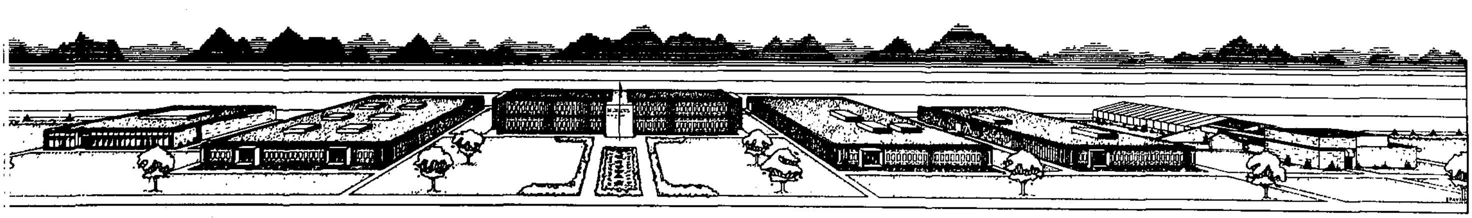
November 1970



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ABSTRACT

A description of the design and construction of a meter capable of measuring scattered levels of irradiance (power density) resulting from the operation of low power, continuous wave, helium-neon gas lasers is presented. Readily available components are used and the techniques for calibration and use of the instrument are discussed. The instrument responds to irradiances of 10 μW/cm^2 or greater depending on the aperture size selected by the user.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation for the assistance of Mr. Mason McNinch in the testing and evaluation of photoconductive detectors and for his aid in constructing the prototype.

The efforts of Miss Anne Roberts in the preparation of figures and in reviewing the text are gratefully acknowledged.

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INTRODUCTION

The increasing availability and use of low power helium-neon laser units has created situations which demand the measurement of irradiance (power per unit area or power density) in order to adequately assess any possible ocular hazards. Commercially available instrumentation is typically designed to provide a large dynamic range of power measurement. Since ocular hazard analysis requires low level irradiance determination, we have designed, constructed and tested an instrument which determines irradiance directly at the helium-neon laser wavelength, 632.8 nm (nanometers), over a narrow dynamic range of irradiance values centered about that value considered to denote the maximum allowable irradiance.

TECHNICAL CONSIDERATIONS

Lasers produce a highly collimated, coherent beam of light. In the visible region of the electromagnetic spectrum the human eye is the organ of critical concern. Relatively low irradiance levels can be concentrated by the focusing action of the cornea and the lens of the eye, which result in irradiances on the retina on the order of 100,000 times greater than the corneal irradiance. In evaluating ocular hazards one is interested only in the measurement of potentially hazardous exposure levels to the exterior of the eye, and detection instrumentation must be designed to respond reliably to the corneal (or low level) irradiance; response to those high levels of irradiance which will produce observable lesions on retinal tissue is then not necessary. Since direct laser beam levels generally exceed (by several orders of magnitude) (acceptable) corneal levels, measurements will routinely be made on scattered levels. An inexpensive photoconductive detector was selected for use in the instrument because of its high sensitivity, its speed of response as well as the success achieved in its use in commercially produced photographic light meters. While the detector could have been used to provide a measurement of power only, the measurement of irradiance was achieved through the use of an aperture of known dimensions. To minimize the effects of any uneven responses across the surfaces of the detector, a lens and diffusing screen were necessary to provide uniform surface illumination. Finally, the response of the detector to a large range of wavelengths required a filter between the aperture and detector which passes only those wavelengths at or near the wavelength of interest (632.8 nm).

At this time the U.S. Public Health Service does not advocate or endorse any published set of laser exposure standards, guides or recommendations. The design of the prototype meter was therefore based on the premise that an internally adjustable control would be necessary to center the response of the instrument at any irradiance which might be typical of the various published recommendations. This control can be eliminated at such time that a single hazard irradiance level is adopted.

Experience with optical power meters has indicated that alignment of a detector for maximum readings is very difficult if the only indication is on a meter, since the operator must devote his attention to two points simultaneously. Since the meter is intended for survey applications, its design includes an audible indicator to allow the surveyor to devote his attention solely to the alignment of the detector with respect to the radiation to be measured.

To achieve maximum utility, the meter, which is capable of field operation, has a minimum weight and no external power requirements. The size and ruggedness is such that the entire instrument can be operated and held in one hand.

CONSTRUCTION

1. Detector Circuit:

The detector circuit, in its most elementary form, is the series circuit shown in Figure 1. The conductance of the detector is proportional to the total power of the light incident on the photoconductive surface, which is deposited on an inner surface of the detector. Thus, the current in the meter is related to the incident light power.

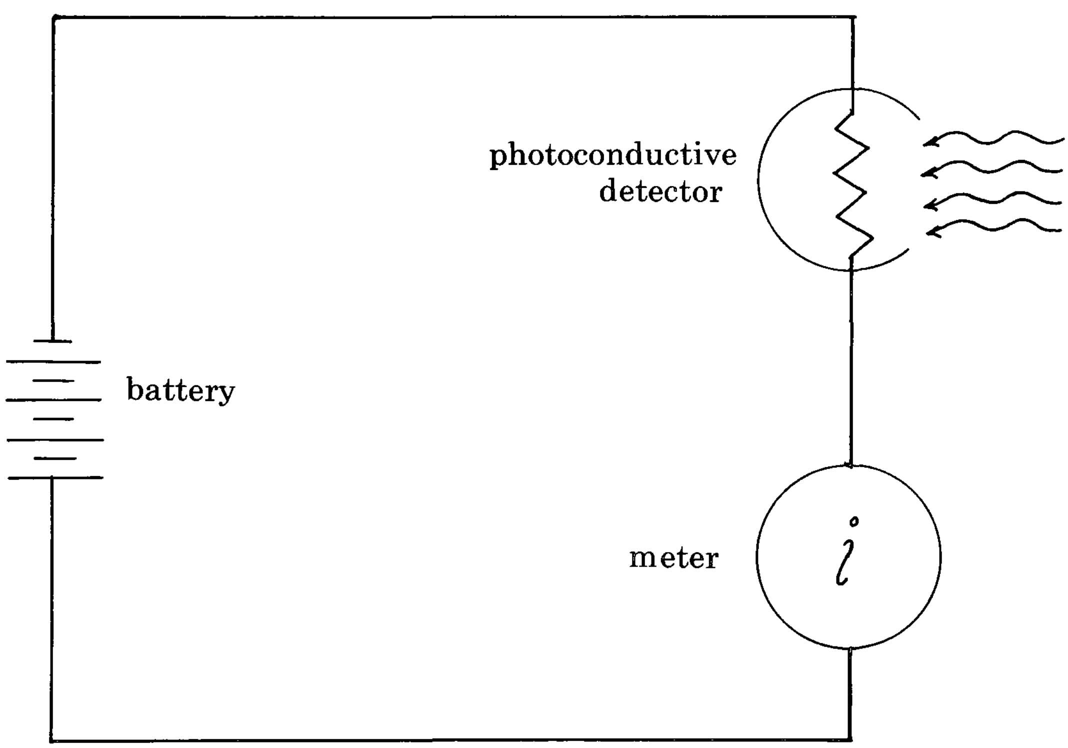
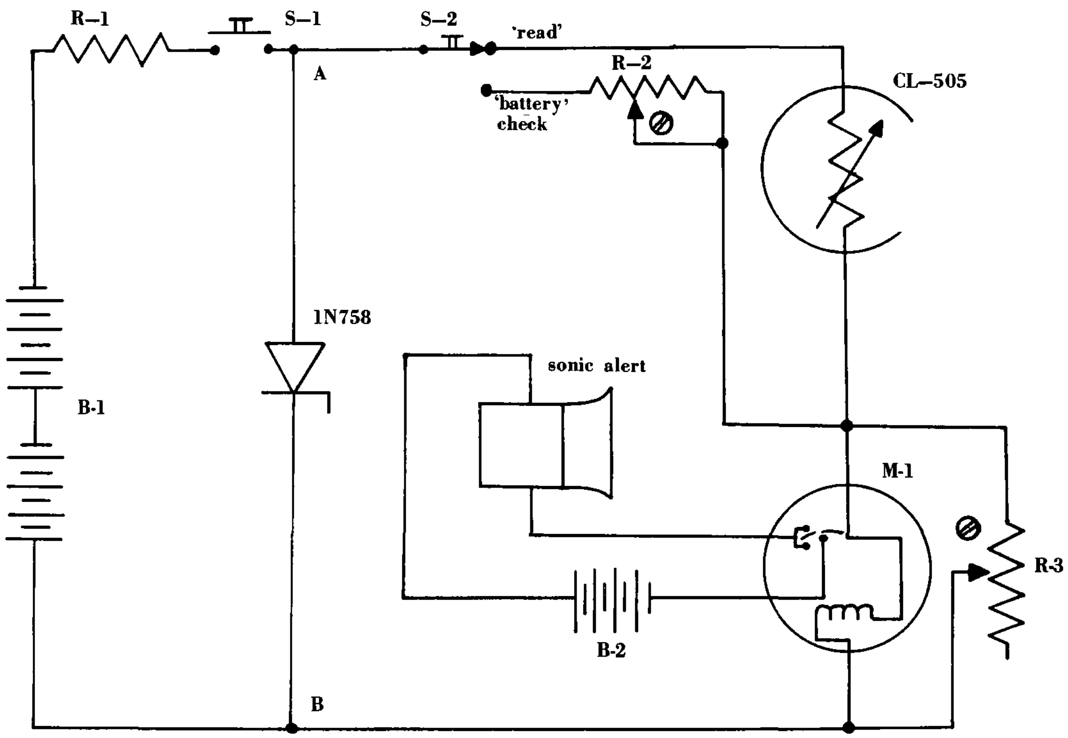


Figure 1. BASIC DETECTOR CIRCUIT

The complete detector circuit schematic is shown in Figure 2. To provide a constant voltage source, a limiting resistor, R_l, and Zener diode have been added. The Zener diode regulates the potential between points "a" and "b" at 10 volts as long as the battery voltage remains slightly above this level. Failure of the battery, B_1, can be monitored by constructing a voltmeter circuit which can be introduced across points "a" and "b" by S-2, a push-button switch. The variable series resistor, R_2, can be set to provide a full-scale indication when the batteries are new and the potential "a" to "b" is 10 volts. Any subsequent test of battery indication which results in less than a full-scale deflection shows battery degeneration and indicates the need for replacement of the meter supply batteries. The variable parallel resistor, R_3, provides a method of adjusting the meter response to the appropriate point such that the midpoint of meter deflection will indicate that level of irradiance considered to be hazardous.

Figure 2. COMPLETE DETECTOR CIRCUIT



Selection of a meter with internal relay points (adjustable from 0 to full-scale triggering) was based on the need for an alternate indicator mode. This mode is an audible signal furnished by a small oscillator and speaker which produces a signal at about 3,000 Hz. A second battery, B_2, is used to power this device. The operability of this segment of the circuit is easily verified by adjusting the relay trigger point to zero deflection on the meter.

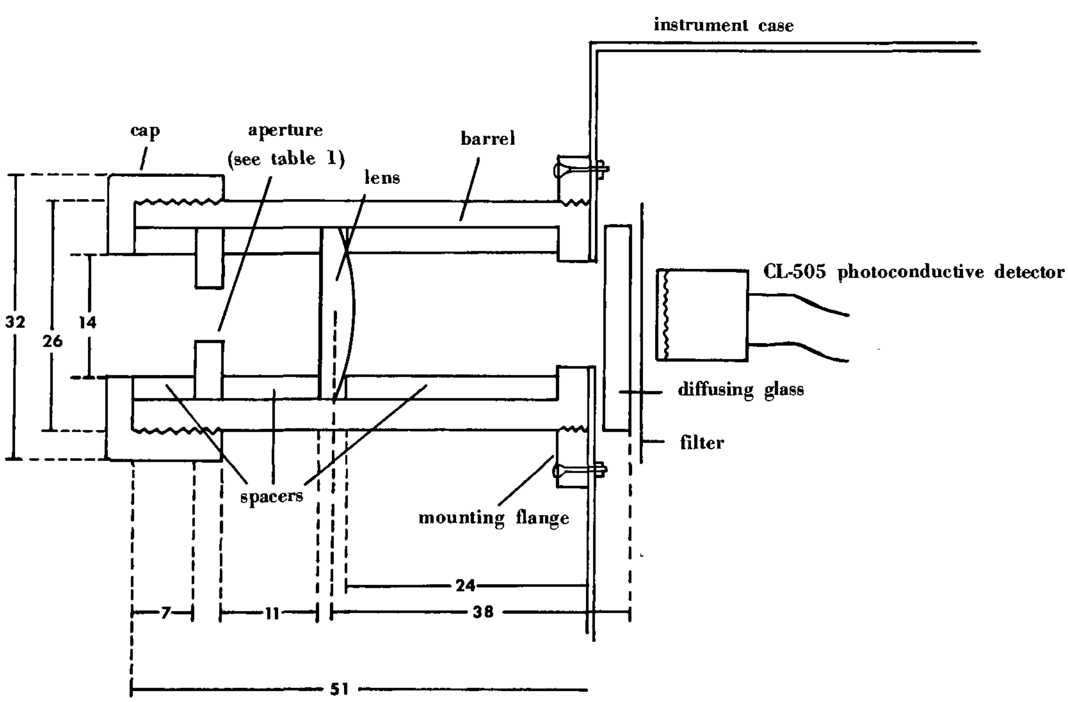
2. Optical System:

As noted earlier, the hazard meter must be designed to respond to irradiance (power density) and not to total optical power at the point of interest. This is achieved by using the optical system shown in Figure 3. Although the aperture must be of known size, the section of the size is dependent only on:

1) the uniformity of irradiance across the aperture and,

2) the sensitivity required of the system.

Figure 3. OPTICAL SYSTEM
all dimensions in millimeters
(machined parts aluminum)



Several apertures have been used and their characteristics are listed in Table I:

TABLE I

APERTURE DIAMETERS AND AREAS

Aperture No.	Diameter	Area
1	1.46 cm	1.67 cm^2
2	1.12 cm	0.99 cm^2
3	0.56 cm	0.25 cm^2
4	0.21 cm	0.035 cm^2

All internal surfaces of the collimator have been sprayed with a velvet black diffuse paint to minimize internal reflections. The lens is positioned so that the focal point falls at the diffusing glass. This provides a well defined acceptance angle and eases the problem of spurious responses from light entering the detector from directions not along the axis of the light beam to be measured. The angular acceptance width to the half maximum response points (FWHM as indicated in Figure 4) is approximately 12° for all apertures evaluated.

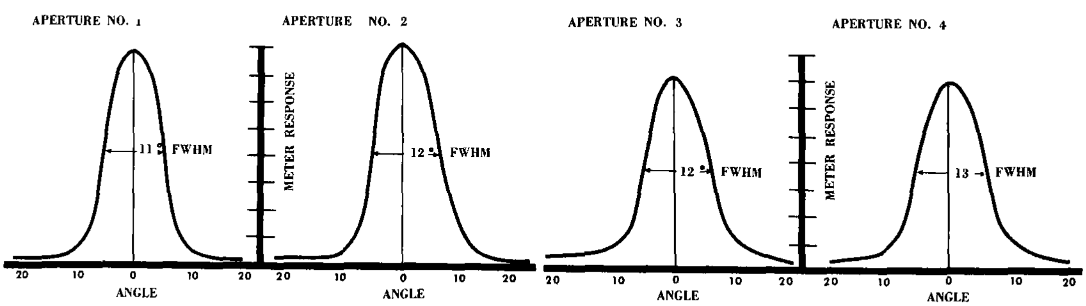


Figure 4. METER RESPONSE vs. ANGLE OF INCIDENCE

3. Assembly:

The assembled configuration of the laser hazard meter is shown in Figures 5 and 6. The system is contained in a 5-inch long by 4-inch wide by 3-inch deep aluminum box. No attempt was made in this prototype to utilize miniature components and it is apparent that even this small size could be further reduced. The internal controls, R_2 and R_3, are accessible through holes on the bottom of the case. In operation, these holes should be covered to reduce stray light leakage to the detector.

CALIBRATION AND OPERATION

The assembled laser hazard meter is calibrated by utilizing an expanded beam from a 2-mW helium-neon laser. Since the irradiance of the cross sectional plane of the beam is approximated by a gaussian distribution, expansion of the beam is necessary to assure a nearly constant irradiance across the aperture. A calibrated power meter, fitted with a variable iris, is used to determine the irradiance at the aperture plane. The beam is then reduced to the irradiance assumed to be hazardous (for example, 10 $\mu W/cm^2$) by inserting calibrated optical filters in the beam. A reference power meter, coupled to the system by a beam splitter, monitors the stability of the laser output during the calibration procedure. The arrangement of the calibration apparatus is shown in Figure 7.

The resistor, R_3, is then adjusted to give half-scale response. The linearity of response can be checked by varying the filters in the beam and noting the response of the laser meter (Figure 8), although this is not of great importance since the meter is a single point, threshold device.

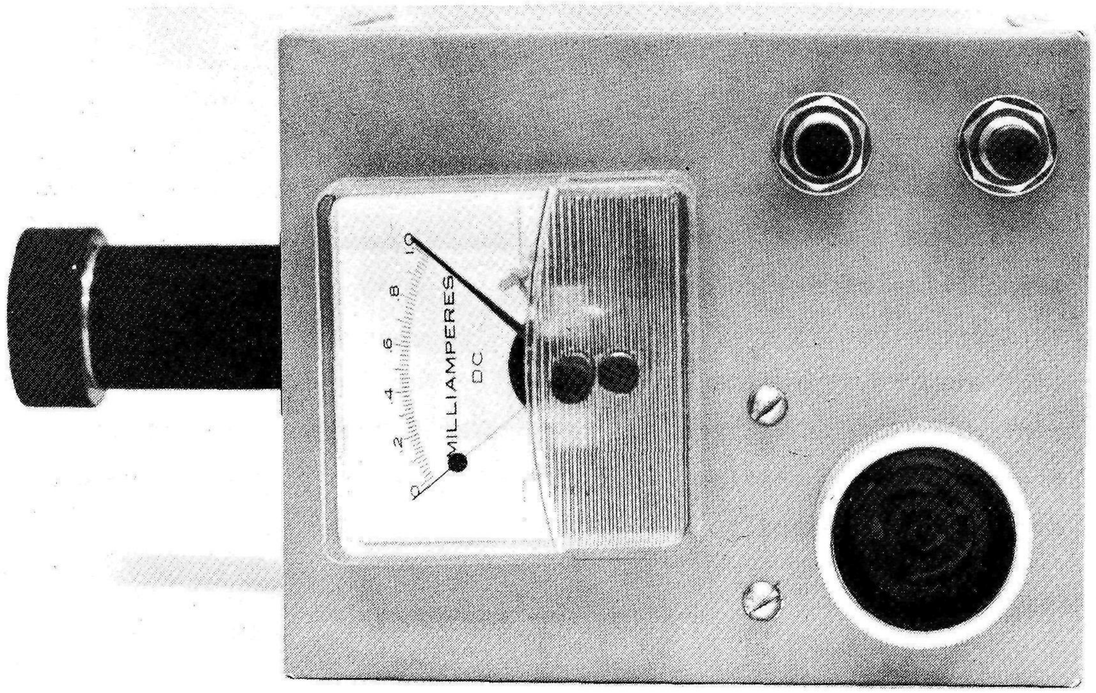


Figure 5. EXTERNAL VIEW OF THE ASSEMBLED METER

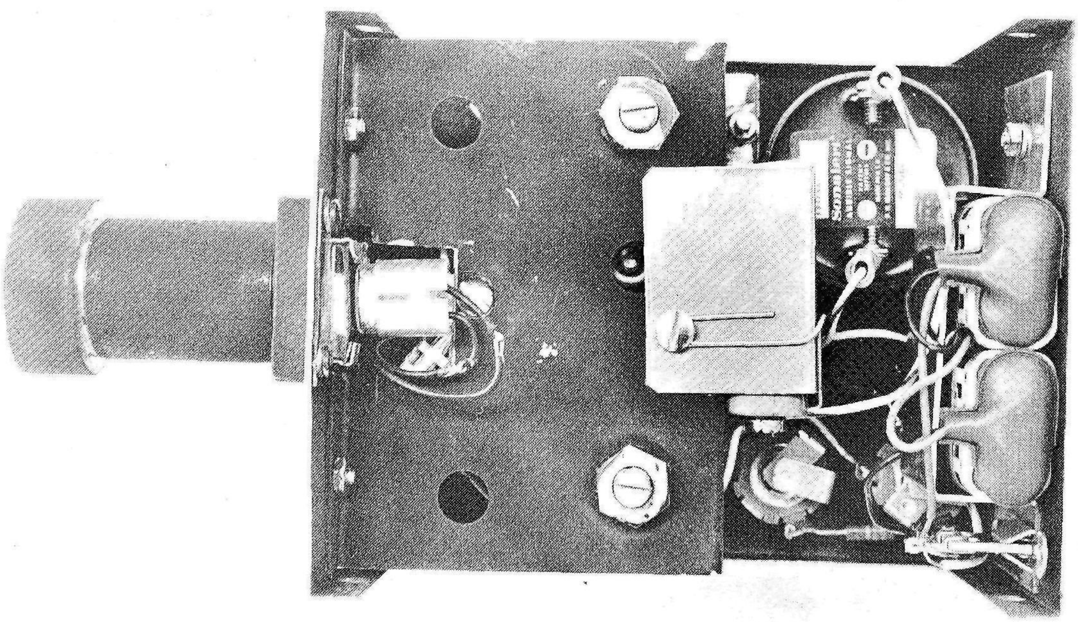


Figure 6. INTERNAL VIEW OF THE METER

Figure 7. ARRANGEMENT OF APPARATUS FOR CALIBRATION

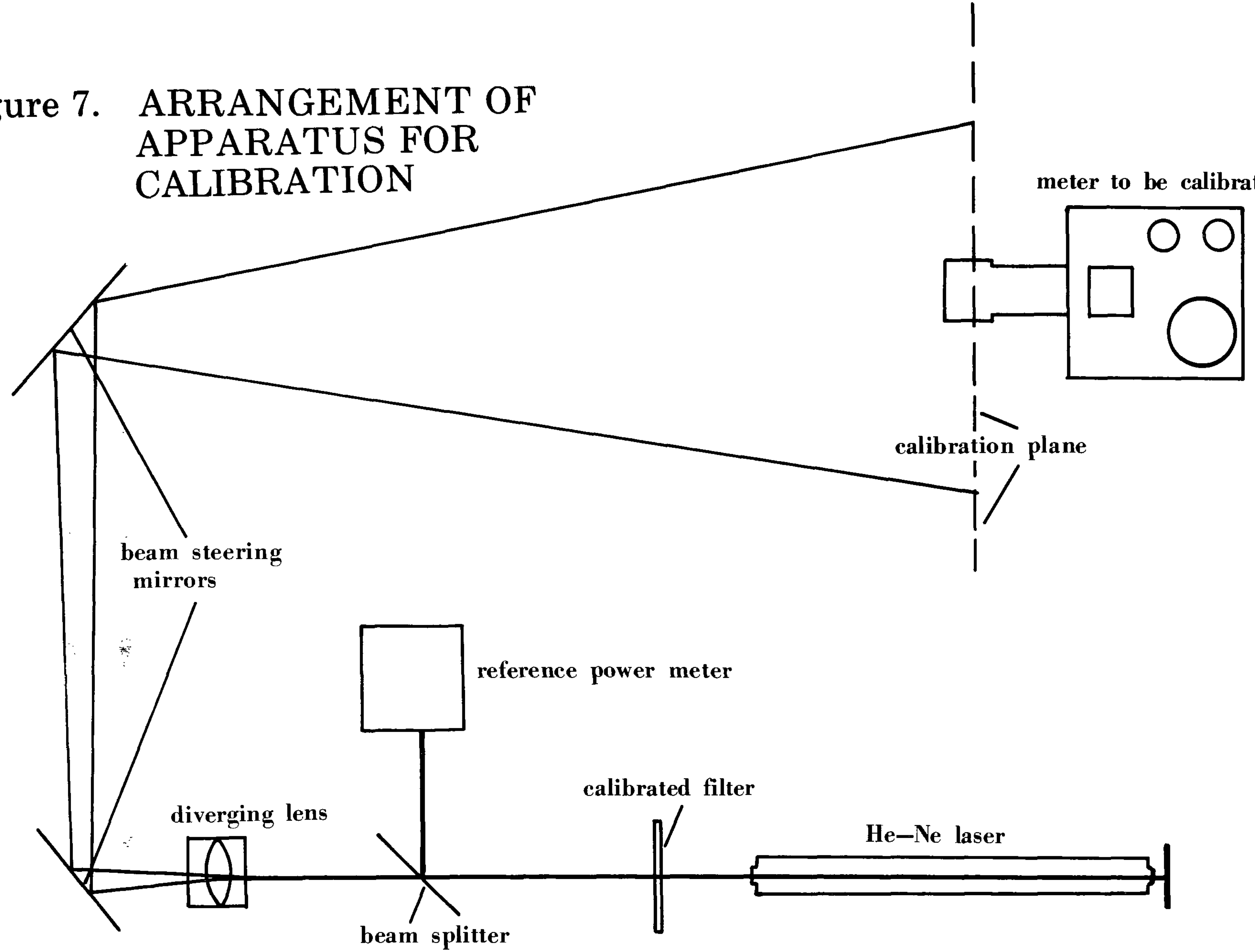
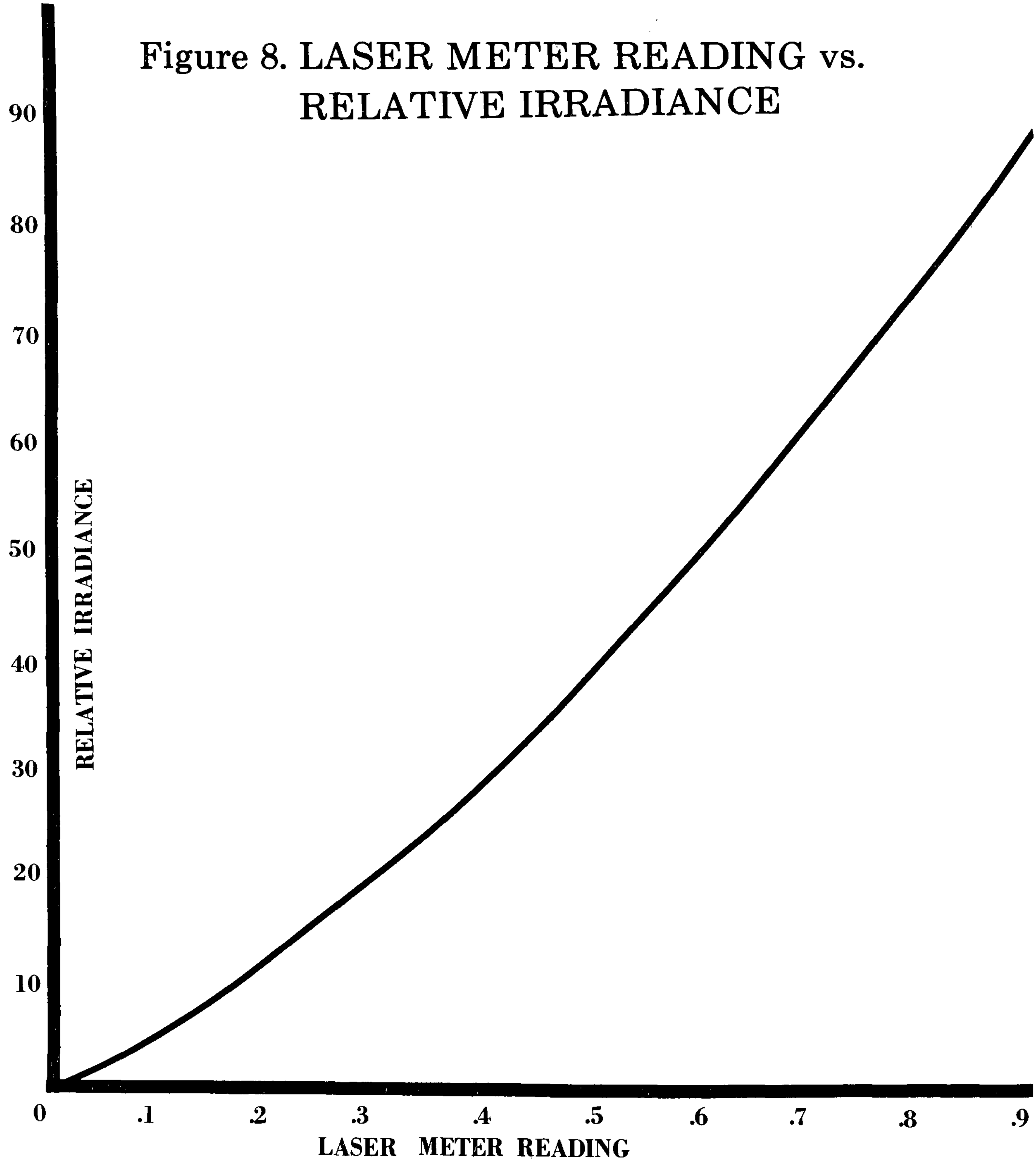


Figure 8. LASER METER READING vs. RELATIVE IRRADIANCE



Finally, the battery metering adjustment, R_2, is adjusted for full-scale deflection. This calibration procedure requires the use of a reasonably well-equipped laboratory.

In practice, the operator aligns the meter with the beam of light at the position of interest. By setting the relay contacts to trigger at half-scale, the sonic alert will sound at any time the irradiance exceeds the hazardous level.

The operational life of the meter circuit batteries should be a minimum of 10 hours as based on the battery manufacturers' specifications if the unit is operated at normal room temperature. Since measurements are generally of short duration, several months of routine operation will be obtainable before the batteries must be replaced. Replacement of the cells in the field (facilitated by the use of readily available 9V transistor radio batteries) will not change the instrument calibration because of the Zener diode regulator circuit.

DISCUSSION

Use of the laser meter has proven to be straightforward. The prime restriction that the entire aperture be uniformly illuminated remains. This restriction becomes of lesser importance as the aperture area decreases. Only beams having diameters less than the aperture cannot be measured with the meter. Since this condition generally exists only in the direct beam (which is assumed to be dangerous) measurement can be made of most scattered light (from either diffuse or specular surfaces). Specular reflections from flat surfaces retain the divergence characteristics of the incident beam and must be analyzed by other techniques.

Aperture dimensions used in the prototype were randomly selected. If one were to utilize the meter for measurement of the ACGIH[1] guide levels, for example, of 50, 20 and 10 $\mu W/cm^2$ (based on ambient lighting conditions) then three apertures of relative areas 0.2, 0.5 and 1.0 might be used. It is then necessary to calibrate at only one level (say 10 $\mu W/cm^2$) and by appropriate choice of aperture any of the other guide levels would also be calibrated.

The detector selected has a spectral response as shown in Figure 9[2]. When the unit is calibrated at 632.8 nm it should not be used for other wavelengths due to the rapid change in detector response as a function of wavelength. The detector has held its calibration with no measurable change over a period of 60 days. Tests in which the detector was continuously illuminated over an eight-hour period by 20 $\mu W/cm^2$ at 632.8 nm failed to produce any calibration shift. The detector exhibits a change in conductance of 7 percent over a temperature range of 0°C to 50°C.[2]

Ambient light does contribute to the meter response. Typical room illumination contributes between 5 to 10 percent of scale response, which has been found to be an insignificant contribution because of the nonlinearity at low levels.

CONCLUSIONS

The feasibility of a portable instrument suitable for detecting hazardous levels of continuous wave laser radiation at 632.8 nm has been demonstrated. Utilization of the instrument provides a convenient method of detecting hazardous levels of reflected or scattered light.

The instrument is stable, easy to use and can be constructed from readily available electronic components.

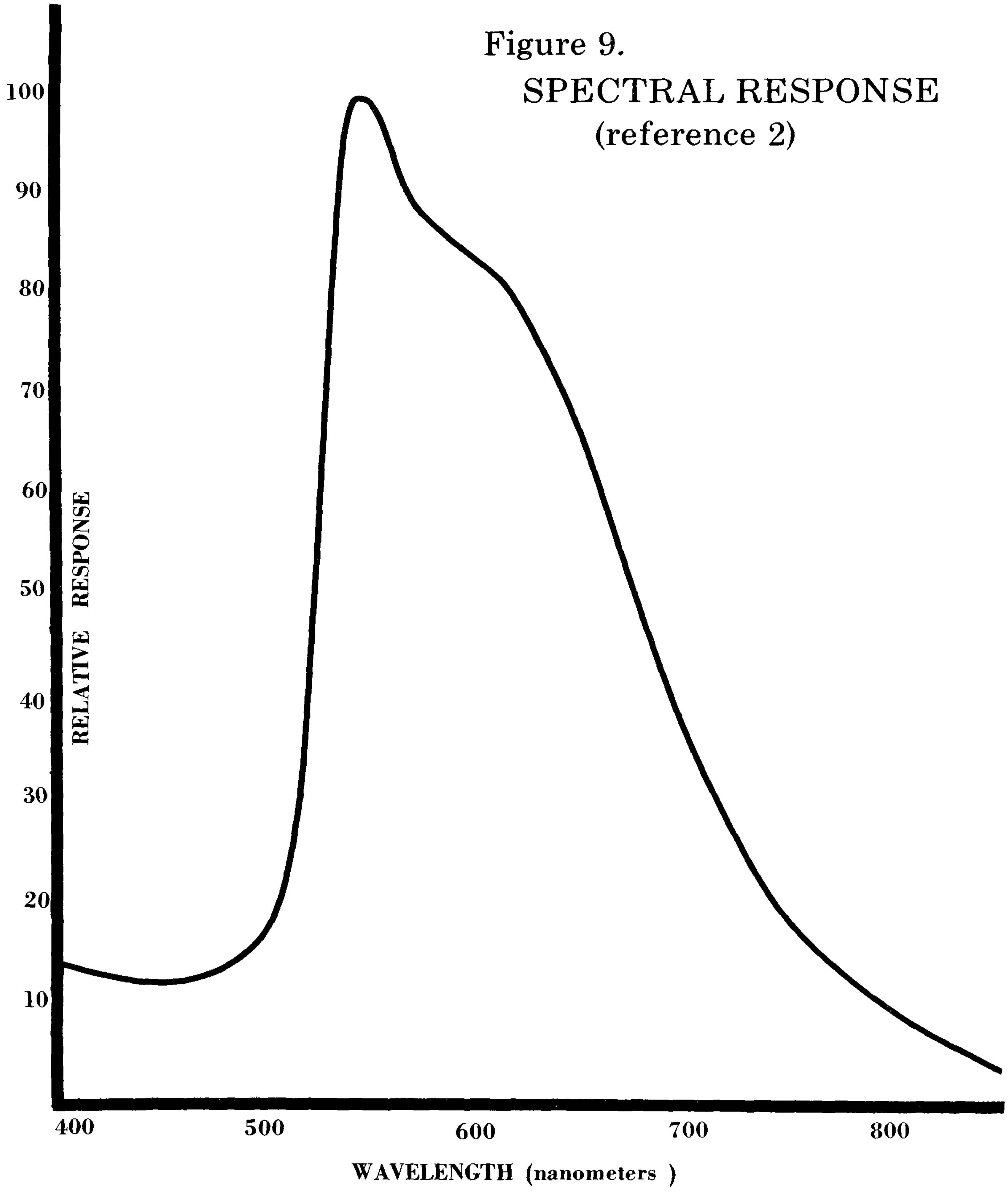


Figure 9.
SPECTRAL RESPONSE
(reference 2)
100
90
80
70
60
50
40
30
20
10
RELATIVE RESPONSE
400
500
600
700
800
WAVELENGTH (nanometers)

The instrument exhibits those properties of cost, utility, and simplicity of operation which indicate its usefulness for relatively unskilled field survey personnel.

References:

(1) A Guide for Uniform Industrial Hygiene Codes or Regulations for Laser Installations, Issued by The American Conference of Governmental Industrial Hygienists, 1968.

(2) Photoconductive Cell Designers Kit, Essential Technical Data, Clairex Corporation, 8 W. 30th St., New York, New York 10001.

APPENDIX A

COMPONENTS* USED IN THE LASER METER

Detector: Photoconductive cell, Clairex CL-505
Allied Radio 60 D 7458 (1.50)

Batteries (3): NEDA 1604D (9V). Allied Radio 18 D 5769 (2.05)

Battery Clips (3): Allied Radio 18 D 5184 (4.20)

Resistors: R-1 500 ohm, 1/2 watt, 20 percent fixed (0.36)
R-2 10,000 ohm, 2 watt, variable (1.60)
R-3 1,000 ohm, 2 watt, variable (1.60)

Switches: S-1 SPST, Push Button, Black, Allied Radio 56 D 9947 (0.65)

S-2 SPDT, Push Button, Red, Allied Radio 56 D 4946 (0.65)

Diode: D-1, 10 V Zener reference Diode, Type IN758 (1.00)

Meter: M-1, 0-1 mA DC, internal magnetic relay, API Instruments Model 202M. Allied Radio 51 D 5584 (37.00)

Sonic Alert: Mallory Sonalert Model SC628. Allied Radio 60 D 8983 (5.50)

Case: Aluminum Minibox. Bud No. CU02105-A. Allied Radio 42 D 7621 (1.50)

Lens: Plano Convex. Diameter 19.5 mm, Focal length 38 mm Edmund Scientific No. 94,035 (0.60)

Optical Housing: Machine from stock (see Figure 3). (cost variable)

Filter: 1" x 1", cut from Rubylith filter gel.

Diffusing glass: 1" x 1", but from 4" x 6" piece of 1/8" opal glass. (1.00)

Paint: 3-M Nextel Velvet Black (2.40 per can)

Equivalent components may be substituted for any of the models specifically designated above.

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* Mention of commercial products used in connection with work reported in this article does not constitute an endorsement by the Public Health Service.

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