



Laser Speed of Light Apparatus

Model No. AP-8586

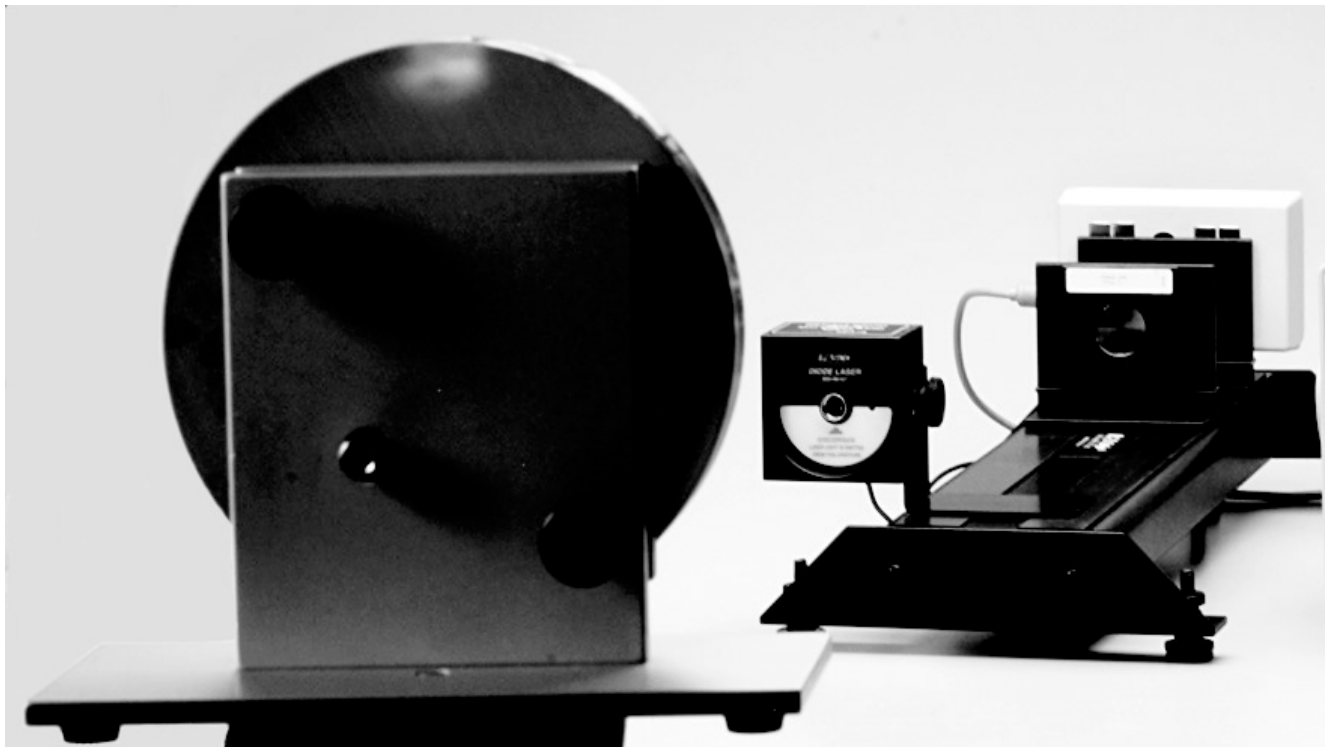


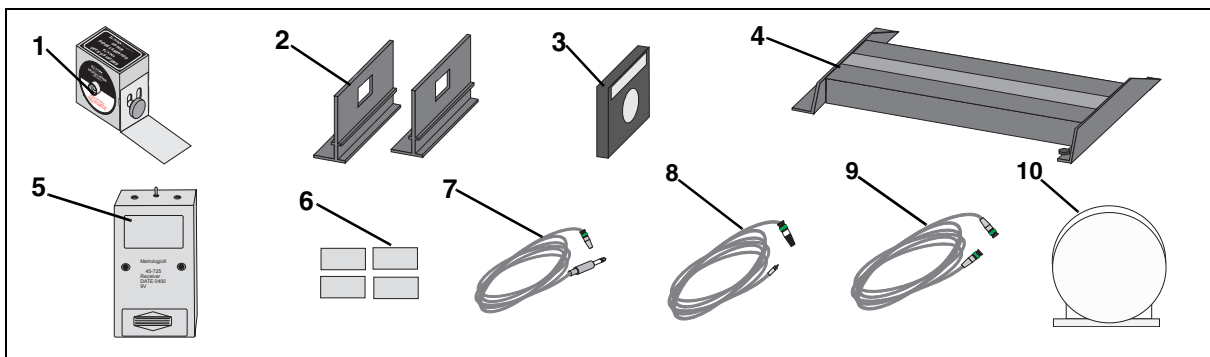
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Laser Speed of Light System

Model No. AP-8586

Equipment List



Included Equipment	Replacement Model Number*
1. Diode Laser with power adapter (1)	OS-8528A
2. Component Carrier (2)	OS-9107
3. Lens, +127 mm (1)	OS-9134
4. Laser Alignment Bench (1)	OS-9172
5. Light Receiver (1)	†See note
6. Stainless steel pads (4)	OS-9148
7. Cable, coaxial, RCA male to BNC male (1)	†See note
8. Cable, coaxial, 3.5 mm phone plug to BNC male (1)	†See note
9. Cable, coaxial, BNC to male (1)	†See note
10. Concave Mirror Assembly (1)	003-02226

*Use Replacement Model Numbers to expedite replacement orders.

†Contact Pasco for replacement of items (see page 15 for contact information).

Equipment List (Continued)

Additional Equipment Required (for experiments)	Replacement Model Number*
Function Generator, wide range	SB-9549A
Oscilloscope, 60 MHz	NA
Tripod	NA
Tape measure	SE-8172A
Tape (for marking floor)	NA
Plumb bob (for indicating mirror position)	NA
Laser Safety Goggles or protective shields (recommended, but not required)**	NA

NA = not available from PASCO scientific

** See Appendix C: Laser Safety for more information about safety goggles.

About the Equipment:

Diode Laser - The diode laser emits an intense, narrowly-focused beam of light. In this experiment, the diode laser is powered by a function generator, which modulates the light intensity at approximately 3 MHz. The laser is equipped with adjustment screws for precisely aiming the light at the mirror.

Concave mirror - The concave surface of the mirror helps to focus the light as it is reflected. The mirror is also equipped with adjustment screws for aiming the light back to the receiver.

Light Receiver - The receiver is designed for receiving audio and video signals transmitted via modulated light. Since the light receiver is sensitive to very high-frequency modulation, it is ideally suited to the experiment in this manual. There are two sensitive elements on the receiver; in this experiment, you will use only the one labeled "Video."

+127 mm Lens - The lens is used to focus the light onto the sensitive element of the receiver.

Introduction

The velocity of light in free space is an important and intriguing constant of nature. Whether the light comes from a laser on a desktop or from a star that is hurling away at fantastic speeds, the velocity of light will yield the same constant value. In more precise terminology, the velocity of light is independent of the relative velocities of the light source and the observer.

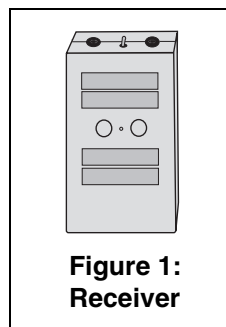
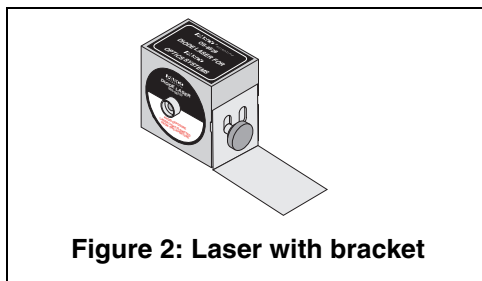
As Einstein first presented in his Special Theory of Relativity, the speed of light is critically important in some surprising ways:

1. The velocity of light establishes an upper limit to the velocity that may be imparted to any object.
2. Objects moving near the velocity of light follow a set of physical laws drastically different, not only from Newton's Laws, but from the basic assumptions of human intuition.

It is not surprising that a great deal of time and effort has been invested in measuring the speed of light. Some of the most accurate measurements were made by Albert Michelson between 1926 and 1929. Michelson measured the velocity of light in air to be 2.99712×10^8 m/sec. From this result, he deduced the velocity in free space to be 2.99796×10^8 m/sec.

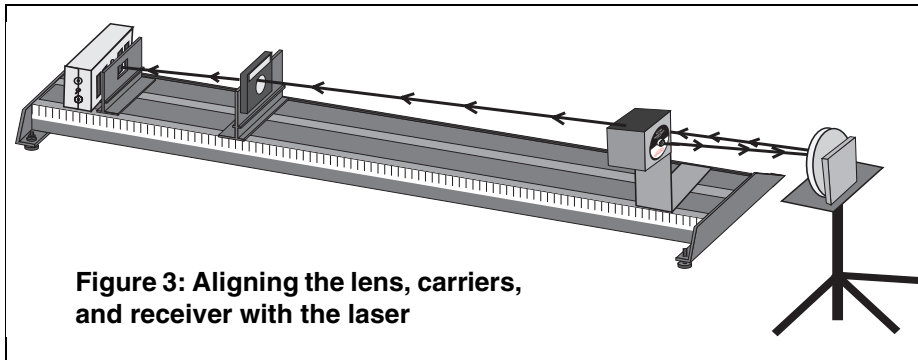
Equipment Setup

1. Stick four stainless steel strips to the front of the receiver (**Figure 1**).
2. Mount the laser on its L-shaped bracket, with the bracket bent away from the laser (**Figure 2**).



WARNING: Before setting up your equipment, please inform your students of the hazards of lasers and enforce appropriate safety precautions in your classroom. For more information, see Appendix C: Laser Safety in this manual.

3. Arrange the laser, lens, receiver and two component carriers on the laser alignment bench (Figure 3).



4. Place the alignment bench on a horizontal surface. You will need 10 to 20 m of clear space in front of the laser.
5. Mount the mirror on the tripod and place it a few meters in front of the laser. Adjust the tripod so that the mirror is at the same height as the laser. (see Figure 3 for the setup.)
6. Mark the position of the mirror on the floor with tape. (Attach a plumb bob to the tripod, so that you mark a point directly below the mirror.
7. With tape, mark the floor at regular intervals to about 10-20 meters from the laser. Allow for at least 10 different intervals within the allotted space.
8. Using the BNC male-to-male cable, connect the TTL output of the function generator to channel 1 of the oscilloscope.
9. Using the RCA male-to-BNC male cable, connect the "Video" output of the receiver to channel 2 of the oscilloscope.
10. Using the phone plug-to-BNC male cable, connect the power jack of the laser to the output of the function generator.
11. Set the function generator for a square wave, and press the DC Offset button. Turn the Output and DC Offset knobs completely counterclockwise.
12. Turn the laser switch to the "on" position.
13. On the function generator, turn up the DC Offset knob until you see laser light. **Do not look directly into the laser light!**



WARNING: Never look directly at the laser light source or reflected light, such as from a mirror. Although the laser used in this experiment is of low power, looking directly into the laser light source or its reflected light from a mirror could cause severe eye injuries or burns. To avoid eye injury, do not look directly into the beam of the laser and wear laser protective goggles. When aligning the laser, use the alignment marker. For more information about laser safety, see Appendix C of this manual.

14. Align the laser, mirror, lens and receiver so that the laser beam is focused onto the “Video” sensing element of the receiver.

15. Set the scope to dual trace:

- a) Set channel 1 to 1v/div., DC.
- b) Set channel 2 to 1 v/div., AC.
- c) Set the trigger to channel 1.
- d) Set the trigger level to about 2.5 volts.
- e) Set the time base to 50 ns/div.

16. Adjust the alignment of the laser, mirror, lens, and receiver to maximize the sine wave signal on channel 2.

17. Adjust the DC offset and amplitude of the function generator to maximize the signal on channel 2.

Experiment 1: Modulated Laser Method for Measuring the Speed of Light

In this experiment, you will measure the speed of light using a laser modulated at a very high frequency and an oscilloscope. You will measure the time, Δt , that elapses while the light signal travels a known distance, Δd , and you will calculate the speed of light, which is defined as $\Delta d / \Delta t$.

The light signal, originating at the laser, will travel to the mirror and back to the light receiver. You will vary Δd by moving the mirror and measuring the corresponding effect on Δt with the oscilloscope.

It is not necessary (or practical) to measure the actual elapsed time, since we are only interested in how Δt changes as Δd varies. Therefore, you will actually measure an elapsed time $\Delta t'$ relative to an



WARNING: Always inform your students of the hazards of lasers and enforce appropriate safety precautions in your classroom. For more information, see Appendix C: Laser Safety in this manual.

arbitrary (but constant) baseline. This elapsed time can be expressed mathematically as:

$$\Delta t' = \Delta t + t_k \text{ (equation 1)}$$

where t_k is an unknown constant. For the same reason, you can also measure d' instead of Δd where

$$\Delta d' = \Delta d + d_k \text{ (equation 2)}$$

The equation of a line fitted to a plot of $\Delta d'$ vs. $\Delta t'$ is

$$\Delta d' = c\Delta t' \text{ (equation 3)}$$

where c represents the slope of the line. The combinations of equations 1, 2, and 3 yields

$$\Delta d = c\Delta t + K \text{ (equation 4)}$$

where K is another arbitrary constant. In equation 4, it is evident that the slope, c , equals $\Delta d / \Delta t$, which is the speed of light.

Procedure

1. Adjust the alignments of the laser and mirror and the positions of the lens and receiver to maximize the signal. (Adjust the receiver up, down, left and right on the carrier, but do not change the position of the carrier on the bench.)
2. On the oscilloscope, adjust the scale and vertical position of the signal to maximize the signal trace. *Do not change the horizontal position of the trace.*
3. Record the position of the mirror (relative to its initial position) and the phase of the signal in Table 1a. If your oscilloscope is equipped with cursors, use them to measure the phase. Otherwise, estimate the phase to 1/2 of the smallest division on the time scale.
4. Move the mirror back to the next mark and repeat steps 1 through 4.

Table 1a

Mirror Position (m)	Phase (s)

Analysis

Plot $\Delta t'$ vs. $\Delta d'$. (Remember that $\Delta d'$ is two times the mirror position. The slope of the best-fit line is the speed of light.

Note: You can plot your data and obtain the best-fit line using DataStudio. For instructions, see Appendix B of this manual.

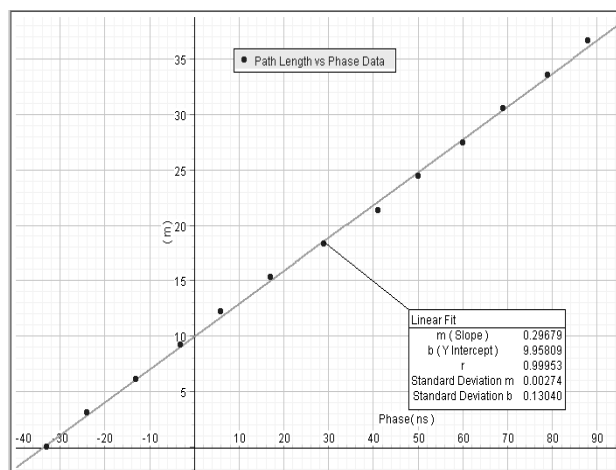
Sample Data

Table 1: Path Length vs. Phase

♥ Path Length vs Phase
Data

Phase (ns)	Path Length (m)
-33.000	0.000
-24.000	3.052
-13.000	6.105
-3.000	9.157
6.000	12.209
17.000	15.262
29.000	18.314
41.000	21.366
50.000	24.419
60.000	27.471
69.000	30.523
79.000	33.576
88.000	36.628

Path Length vs. Phase Data



Appendix A: Specifications

Component	Description
Diode Laser	1 mw, 650 nm
Component Carrier	6.3 cm (height) x 7.6 cm (length); 3.8 cm x 7.5 cm (base)
Lens	127 mm
Laser Alignment Bench	38.8 cm length
Metrologic Light Receiver	10.2 cm x 6.2 cm x 4.2 cm; two channel output (one audio, one video), dual light sensors, 9 VDC
Stainless steel pads	0.97 x 4.5 cm, rectangular, stainless steel
Cable, coaxial, RCA male to BNC male	183 +/- 2.5 cm length
Cable, coaxial, 3.5 mm phone plug to BNC male	183 +/- 2.5 cm length
Cable, coaxial, BNC to male	183 +/- 2.5 cm length
Concave Mirror Assembly	13.5 meters

Appendix B: Plotting Data in DataStudio

The following instructions are provided for new users or those unfamiliar with DataStudio. The following instructions explain how to create an x-y graph and/or calculate statistics on previously collected data.

1. Open DataStudio. When the Welcome to DataStudio window opens, select “Enter Data.” An editable table and Graph display open.
2. On the main toolbar, click the **Summary** button.
3. In the Data list, double click on the data icon to open the Data Properties dialog.
4. In the Data Properties dialog, do the following:
 - a) Enter a name for your experiment in the **Name** box.
 - b) Click on the **X tab** and enter the variable name “Phase” to label the x axis. Enter the units for phase (ns or s).
 - c) Click on the **Y tab** and enter the variable name “Path Length” to label the y axis. Enter the units for length (m). Click **OK**.
5. In the Editable data table, enter your values for phase and path length. The data values automatically plot in the graph to the right.
6. On the graph toolbar, click the **Curve Fit** button and select “Linear Fit.” Slope, intercept, correlation, and standard deviation values appear in a box on your display.

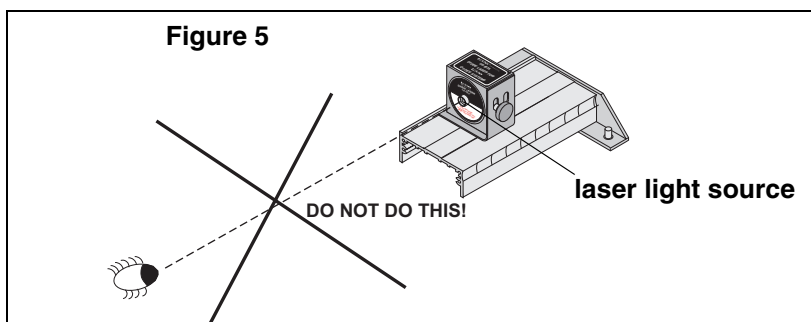
Appendix C: Laser Safety

The OS-8528 is a low power, Class 2 laser. When Class 2 lasers are used in accordance with Occupational Health and Safety Administration (OSHA) standards, Class 2 lasers are not harmful. However, when appropriate safety precautions are not taken, Class 2 lasers can cause permanent, irreversible damage to the eyes, skin, and other body tissues. As an instructor, you should always inform your students of the hazards of lasers and the necessary preventative, safety measures.

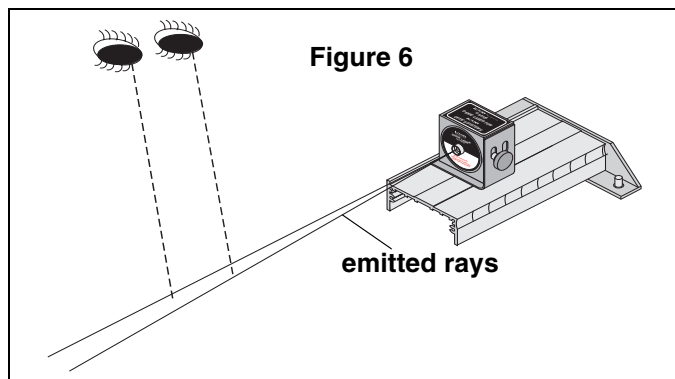
PASCO cannot be held liable for negligent use in the classroom. As a courtesy, we are providing you with the following laser safety instructions. These reminders are not a comprehensive list of all possible safety measures or hazards. For more information, see the OSHA web site (<http://www.osha.gov>). Also see <http://www.safetymanual.com> or www.laserinstitute.org

Safety Reminders:

- Never look directly into the laser or at any reflection from the laser at eye level (see figure 5 below).



- Keep your eyes at least 1 foot above the light source. (see Figure 6).



- Do not place your hand, finger, or any other part of your body directly on the laser. Lasers can burn the skin and damage tissue.
- Do not point a laser at your own eye, through glass, mirrors or transparent objects in your surroundings, or at the eyes of other individuals.
- Never remove any of the covering or components of the AP-8586 Diode Laser. If the laser is defective, return the defective laser immediately to PASCO scientific.
- If you are uncomfortable or unsure about working around lasers, wear protective laser goggles or spectacles.

About Laser Protective Eyewear

The eyewear must be designed for use with lasers and meet OSHA standards specific to the type and class of laser you are using. You can tell if the type of goggle or spectacle you are using meets laser standards by looking at the insignia on the side of the frame. Any type of plastic chemical protective goggle will not suffice. Also, you need to select protective eyewear with the correct filter for the wavelength range of the laser (For a Class 2 laser, you need a 400-780 nm filter.)

Example: Laser goggles designed to protect for Class 1 lasers do not provide maximum protection when using Class 2 lasers. For more information, see the OSHA web site (www.osha.gov).

Laser Injuries

Severe corneal injuries or eye burns may or may not present with pain at the surface of the eye. In retinal injuries, the individual may see red spots, or have blurred vision or altered color perception.

Less severe injuries may not show up immediately and are more hazardous when they occur repetitively.

If you believe you have a laser injury, report the injury immediately to your instructor/supervisor, school health department and/or safety officer. If necessary, go to an emergency health facility or contact a medical doctor or ophthalmologist.

Appendix D: Technical Support

For assistance with the AP-8586 or any other PASCO products, contact PASCO as follows:

Address: PASCO scientific

10101 Foothills Blvd.

Roseville, CA 95747-7100

Phone: 1-800-772-8700 or (916) 786-3800

FAX: (916) 786-3292

Web: www.pasco.com

Email: techsupp@pasco.com

Appendix E: Copyright and Warranty Information

Copyright Notice

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Limited Warranty

PASCO scientific warrants the product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. PASCO will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. The warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of a manufacturing defect or improper use by the customer shall be made solely by PASCO scientific. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packing of the equipment for return shipment will not be covered by the warranty.) Shipping costs for returning the equipment after repair will be paid by PASCO scientific.

