

Diffraction Apparatus

Order Code DAK



The Diffraction Apparatus allows students to measure the intensity as a function of position for various diffraction and interference patterns. The apparatus includes a Red Diffraction Laser, a Diffraction Slit System, and a Combination Linear Position and High Sensitivity Light Sensor. A required accessory is the Combination Dynamics Track and Optics Bench (TRACK), which is also available as a part of the Vernier Dynamics System (VDS). The diffraction components attach to the track.

The Combination Linear Position and High Sensitivity Light Sensor has an analog output for the light sensor, and a digital output for the position sensor. These connect to an interface, such as a LabQuest 2, LabQuest, LabQuest Mini, or LabPro. The pattern can be recorded in Logger Pro¹ software. When used with a LabQuest 2 or LabQuest², the diffraction pattern can be recorded directly on the interface.

An optional Green Diffraction Laser (GDL-DAK), not included with the basic Diffraction Apparatus, allows the study of the impact of light wavelength on diffraction and interference patterns.

With all this equipment, students are able to investigate relationships between

- Slit width and pattern spacing.
- Double slit separation and pattern spacing
- Intensity as a function of position for single slit diffraction
- Intensity as a function of position for double slit interference
- Effect of light wavelength on all patterns

Parts included with the Diffraction Apparatus

- Red Diffraction Laser (635 ±5 nm)
- Diffraction Slit System, with a variety of single slits, double slits, variable slits, and comparison slits
- Combination Linear Position and High Sensitivity Light Sensor
- Power Supply for Laser³

¹ Logger Pro 3.8.5 or newer is required.

² LabQuest App version 1.6 or newer is required.

³ The power supply is interchangeable with that used for the LabQuest interface.

Laser Safety

- This is a class 2 laser product.
- Do not stare directly into the laser beam or its reflection.
- Maximum output is < 1 mW.

A class 2 laser is generally considered safe as the blink reflex will limit exposure to short time periods. Most laser pointers are in this class. Direct exposure on the eye by a beam of laser light should always be avoided with any laser, no matter how low the power.

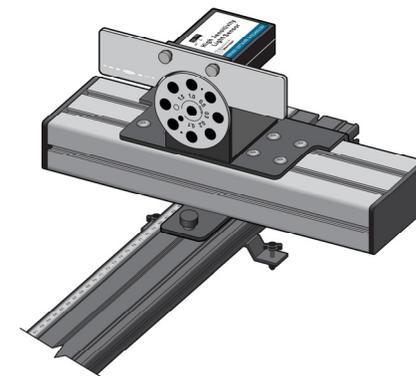
This sensor is equipped with circuitry that supports auto-ID. When used with LabQuest 2, LabQuest, LabQuest Mini, or LabPro, the data-collection software identifies the sensor and uses pre-defined parameters to configure an experiment appropriate to the recognized sensor.

Suggested Initial Diffraction Apparatus Assembly

The laser and slit are at one end of the track, and the combination light sensor and linear position sensor is positioned at the other. The separation allows the interference pattern to spread sufficiently to allow easy measurement of the spacing.

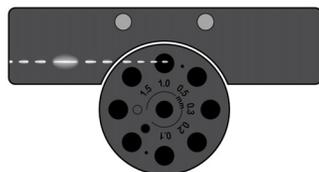
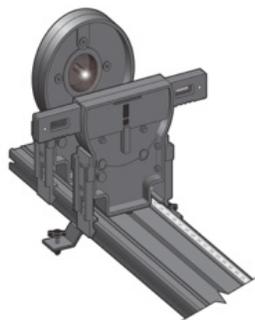


1. Place the dynamics track on a level surface. Use of adjustable feet for the track is convenient, but optional.
2. Attach the Combination Linear Position and High Sensitivity Light Sensor to the track, with the light sensor facing down the length of the track. It is convenient to place the front edge of the position sensor at about the 110 cm mark. The center tabs on the sensor base rest in the center groove of the track. If you have trouble passing the square ¼-20 nuts into the groove, remove them and insert the nuts only, and then attach the sensor base to the track using the supplied bolts and nuts. Slide the light sensor to approximately the center of the position sensor.
3. Set the entrance aperture disk of the light sensor to the 0.3 mm setting, and set the light sensor sensitivity to the middle, 10 μW, setting.
4. Attach the slit assembly to the track, with the label and silver reflective side facing away from the Combination Linear Position and High Sensitivity Light



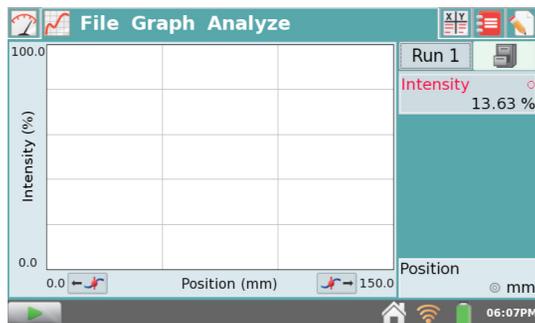
Sensor. A typical starting position is at the 20 cm mark on the track. Select the 0.04/0.25 mm double slit.

- Attach the Red Diffraction Laser to the track, facing the slit assembly. Typical starting position is at the 5 cm mark. As before, if you have trouble passing the square ¼-20 nut into the groove, remove it and insert the nuts only, and then attach the laser. Drive the bolt into the nut.
- Attach the Power Supply to the laser and to an electrical outlet.
- The rocker switch on the back of the laser turns the laser on when the lower edge is depressed. Turn on the laser and confirm that you see red light striking the slit assembly.
- Adjust the vertical and horizontal direction of the laser using the two thumbscrews on the back of the laser, so that the beam passes through the double slit and falls on the light sensor front plate. Roughly center the diffraction pattern on the top entrance aperture of the light sensor.



Data-Collection Overview and Software Setup

Both *Logger Pro* and *LabQuest App* software will detect the presence of the Combination Linear Position and High Sensitivity Light Sensor and set up data collection appropriately. A graph of intensity vs. position is shown by default.



About the Linear Position Sensor

The Linear Position Sensor is based on an optical encoder, similar to the one used in the Vernier Rotary Motion Sensor (RMV-BTD). As the position sensor is moved left and right by hand, a strip of narrow alternating black and clear bands pass an optical sensor. The events are counted and turned into a position reading. The resolution is about 40 μm. There is essentially no backlash, because the system has only one moving part.

Logger Pro and *LabQuest App* will both set the position reading to zero when the software is launched or File | New is chosen. To zero the position sensor, move the position sensor to the far right edge while looking at the light sensor aperture plate.

- On *LabQuest App* meter screen, tap the position meter and choose zero.
- On *Logger Pro*, click the zero button in the toolbar, select only the position sensor, and click ok.

NOTE: Vernier products are designed for educational use. Our products are not designed nor recommended for any industrial, medical, or commercial process such as life support, patient diagnosis, control of a manufacturing process, or industrial testing of any kind.

About the High Sensitivity Light Sensor

The High Sensitivity Light Sensor includes an aperture plate with selectable 0.1, 0.2, 0.3, 0.5, 1.0, and 1.5 mm width entrance slits, as well as full open and full blocked apertures. These slits are used to limit the acceptance of the sensor in the horizontal direction, to optimize the spatial resolution of the overall system. The slit choice is a tradeoff between light quantity and spatial resolution. Faint, broad patterns are best studied with wider slits, while bright, highly detailed patterns will require narrower slits. The 0.5 mm slit is a good place to start. If features in the collected data are on the order of 0.5 mm wide, you may want to try narrower slits. Or, try data collection with a narrower slit to see if the pattern shape changes. Typically the modulation of an interference pattern will increase with narrower slits, but the intensity will decrease.

The light sensor itself has three ranges. The nominal full scale reading corresponds roughly to 1, 10, or 100 μW, as selected. The sensor responds throughout visible wavelengths. However, each range is reported in percent of full scale, or 0 to 100%, as absolute calibration is not relevant to these experiments. It is normal for the sensor to read between 10 and 20% when the sensor is in the dark. Optionally, the light sensor can be zeroed. To do this, rotate the aperture plate to the blank (black circle) position to block all light from the sensor.

- On *LabQuest App* meter screen, tap the light meter and choose zero.
- On *Logger Pro*, click the zero button in the toolbar, select only the light sensor, and click ok.

The light sensor is not designed to be removed from the Linear Position Sensor.

About the Slit Assembly

The slits are made of metal-on-glass films, and so present very clean diffraction and interference patterns.

Available slits

- Single Slits: 0.02, 0.04, 0.08, 0.16 mm width
- Double Slits: 0.04 / 0.25, 0.04 / 0.5, 0.08 / 0.25, 0.08 / 0.5 mm width and separation
- Variable Slits: single slit 0.02 – 0.2 mm width

double slit: 0.04 mm width, variable spacing 0.125 – 0.75 mm

- Multiple Slits: 0.04 mm width, 0.25 mm spacing: 2, 3, 4, 5 slits
- Comparisons: 4 pairs of single/double slits: 0.04 mm single + 0.04/0.25 mm double, doubles 0.04/0.25 + 0.04/0.50, doubles 0.04/0.25+0.08/0.25, double 0.04/0.25 + triple, 0.04/0.25
- Other shapes: Slit and line comparison 0.08 mm slit and opaque line on clear background; 0.20mm and 0.40 mm round holes

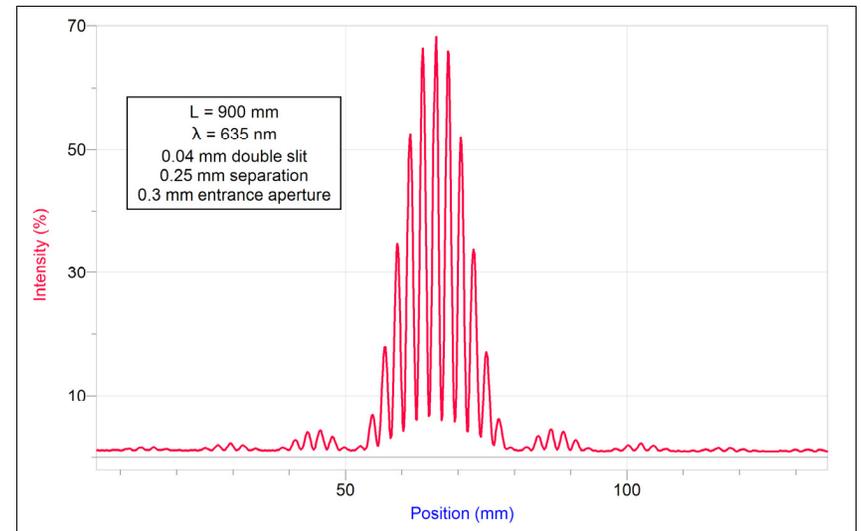
Slit applications

- The single slits, double slits, and multiple slit patterns are designed for quantitative experiment.
- The variable slits cast vertical patterns to be shown on a white surface, and are intended for qualitative viewing. You may choose to let use the screen included with the Vernier Optics Expansion Kit (order code OEK), or available separately as a replacement part (order code SCRNOEK).
- The comparison slits are used by adjusting the laser up and down to compare patterns visually and qualitatively; because the beam won't be fully horizontal, the pattern may not strike the light sensor.
- The slit and line comparison is intended to be used qualitatively, to observe the pattern similarity between that of a single slit and a single opaque line.
- The circular apertures are intended for qualitative viewing of the diffraction pattern from a hole, as opposed to a line.

Basic Data Collection with the Diffraction Apparatus

- Assemble the Diffraction Apparatus as described above.
- Move the position sensor to the far right as viewed from the light sensor side.
- Connect the sensors to an interface, and start the data collection software.
- Start data collection.
- Grasp the position sensor, and slowly and smoothly move the light sensor across the full width of the stage. Take about 30 seconds to perform the motion. If you move too quickly, the light sensor will not have time to respond to variations in the intensity pattern. You can always test your run by storing it, and immediately taking another run. The new run should lie nearly on top of the first one.⁴

⁴ For the LabPro only, the zero will drift if the light sensor is moved in between data collection runs. Re-zero the sensor if needed.

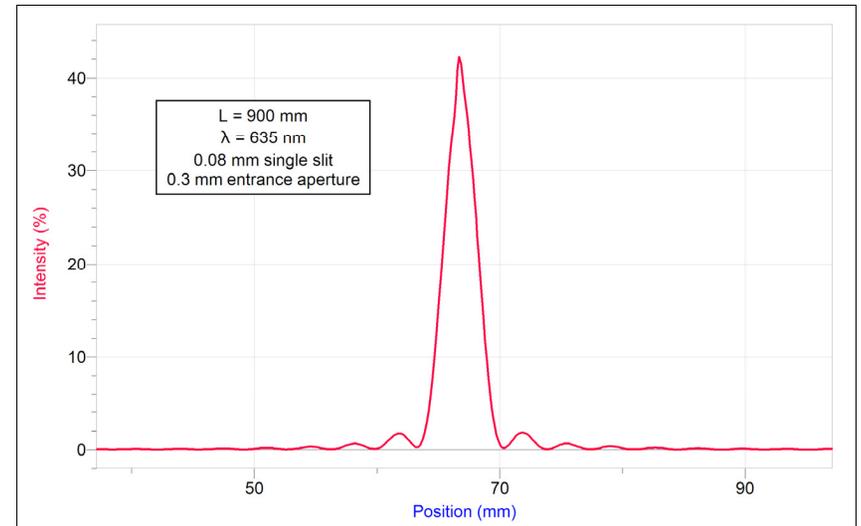


Sample graph of double slit diffraction pattern, with two 0.04 mm slits 0.25 mm apart.

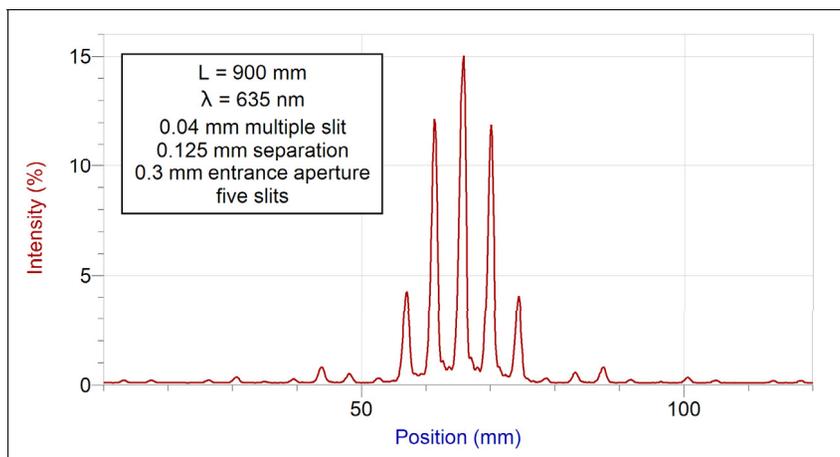
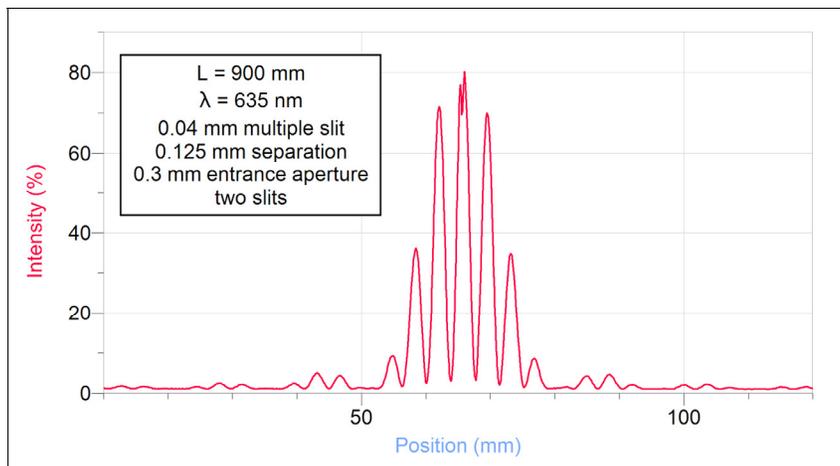
Common Experiments with the Diffraction Apparatus

The variety of slits provided with the Diffraction Apparatus suggests many experiments. In most cases each activity can be done to two depths: the spacing of the dark or light bands can be measured and compared to calculation, or the quantitative shape of the patterns can be compared to calculation.

Detents in the slider assembly hold the selected slit in position during an experiment. The variable slit choices have no detent to allow smoothly changing the slit position.



Sample graph of single slit interference pattern, with one 0.08 mm slit.



Sample graph of multiple slit diffraction pattern, with 0.04 mm slits at a 0.125 mm separation, 2 and 5 slits.

The remaining slits are intended for viewing by eye, and not necessarily doing measurements with the light sensor and position stage.

The slit assembly includes a variable width single slit and a variable separation double slit. To demonstrate the effect of smoothly changing either variable, start with the laser striking roughly in the middle of the pattern, and slide the slit assembly right or left.

Comparison with Theory⁵

Experiments with the Diffraction Apparatus are typically done either as a full model of the intensity distribution of the patterns, or as a simpler search for the locations of bright and dark fringes. The basic models are provided here.

Intensity Distribution

Double-slit interference intensity as a function of angle for slits of width a and separation d is given by

$$I(\theta) = I_m (\cos^2 \beta) \left(\frac{\sin \alpha}{\alpha} \right)^2$$

where

$$\beta = \frac{\pi d}{\lambda} \sin \theta \text{ and } \alpha = \frac{\pi a}{\lambda} \sin \theta$$

I_m is the maximum intensity, and is an overall scale factor. λ is the light wavelength.

Single-slit diffraction for a slit of width a is given by

$$I(\theta) = I_m \left(\frac{\sin \alpha}{\alpha} \right)^2$$

For comparison with data from the Diffraction Apparatus, you will need to apply the small angle approximation. Using a distance L from the slit to the screen (or entrance aperture) along the track, and a position y along the line perpendicular to the track, we have

$$\sin \theta = \frac{y}{L}, \text{ so } \theta \sim \frac{y}{L}$$

since $y \ll L$.

In practice the location of the origin of y axis will vary by a small amount, depending on exactly how the laser is directed. The zero of the position sensor will be very different from the origin location on y .

Occasional differences from theory may occur due to reflections from the glass slits. The reflection may cause the central peak to have a dip or spike in magnitude from expectations. The dip will be very close to the center of the pattern, but may be offset to one side slightly. This is normal.

To compare experimental data with model, adjust the overall scale of the model to match the data, and add a horizontal offset to bring the model in line with the experimental data, which will not be centered on zero.

⁵ Adapted from *Fundamentals of Physics*, 9th edition, Halliday and Resnick, Wiley, 2011.

Fringe Location Only

The locations of the dark fringes in a single slit are give by

$$a \sin \theta = m\lambda, \text{ where } m = 1, 2, 3 \dots$$

For a double slit, the bright fringe locations are given by

$$d \sin \theta = m_2 \lambda, \text{ where } m_2 = 0, 1, 2 \dots$$

In short, the distance from one dark fringe to the next in single slit diffraction is $\lambda L/a$, and the distance from one bright fringe to the next in double slit interference is $\lambda L/d$.

Software and Interface Requirements

Logger Pro 3 Use this computer program with LabQuest 2, LabQuest, LabQuest Mini, and LabPro. Version 3.8.5 or newer is required. See <http://www.vernier.com/tech/lpupdates.html> for free updates to Logger Pro.

LabQuest App Use this program with LabQuest 2 or original LabQuest when it is used as a standalone device. Version 1.6 is required for the original LabQuest. Updates to LabQuest are free and can be downloaded from <http://www.vernier.com/labquest/updates/>

Specifications

Red Laser Wavelength: 635 ± 5 nm

Optional Green Laser Wavelength 532 ± 1 nm

Light Sensor Full Scale Ranges: 1, 10, and $100 \mu\text{W}$

Linear Position Sensor range: 150 mm

Linear Position Sensor resolution: $40 \mu\text{m}$

Other Products for Use with this Kit

Combination 1.2 m Dynamics Track/Optics Bench (TRACK)

Optics bench required for use with the Diffraction Apparatus. The same part is included with the Vernier Dynamics System (VDS).

Green Diffraction Laser (GDL-DAK)

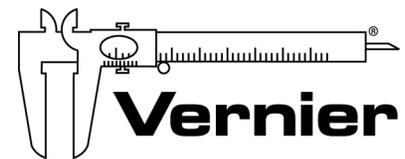
Add an optional second laser wavelength to the Diffraction Apparatus. 532 ± 1 nm. Use the same power supply as the Red Diffraction Laser.

Replacement Screen for Optics Expansion Kit (SCRN-OEK)

Add an optional white screen for qualitative viewing of diffraction and interference patterns. The same screen is a part of the Optics Expansion Kit (OEK).

Warranty

Vernier warrants this product to be free from defects in materials and workmanship for a period of five years from the date of shipment to the customer. This warranty does not cover damage to the product caused by abuse or improper use.



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