Two Slit Interference

Equipment Teach Spin two slit interference apparatus, Teach Spin Cricket, Fluke multimeter with BNC to banana plug leads, Tektronix TD 1002 scope and manual, 2 BNC to BNC cables, Tenma 72-4095 counter, small mirror, toothpicks, TeachSpin "T" cards for observing light beam, plastic alignment jig, flashlight with pencil beam, magnifying glass

MUST Reading "The Feynman Lectures on Physics", R.P. Feynman, R.B. Leighton, and M. Sands (Addison Wesley 1965) or Vol. I, Ch. 37; Vol. III, ch. 1. These two chapters are essentially identical.

Review Reading From a textbook, one and two slit interference patterns

PRECAUTIONS

1. PHOTOMULTIPLIER TUBE- This tube can be damaged or destroyed if exposed to all but the weakest light, *even if* voltage is not applied to the tube. The tube is protected by a shutter. The shutter is opened by raising a rod at the detector end of the apparatus. The rod has a BNC cable coming out the top of it. This shutter should not be opened unless:

   - the cover is on the apparatus and properly secured with the 4 "L" latches.
   - the Laser-Off-Bulb switch is in the off position
   - the potentiometer controlling the intensity of the bulb source is fully CCW (dial at zero).
   - the switch that turns on the photomultiplier tube (PMT) voltage is in the off position.
   - the multi-turn potentiometer controlling the PMT voltage is fully CCW (dial at zero)
   - the photomultiplier output is monitored on the scope.

   There is no need to open the shutter until you reach a certain point in the experiment. At that point, this lab manual will specifically instruct you to open the shutter AFTER reviewing the above precautions. DO NOT OPEN THE SHUTTER UNTIL THIS MANUAL TELLS YOU TO. The photomultiplier tube protected by the shutter costs hundreds of dollars and delivery time may delay your experiment, in which case you will need to return to the lab on a different weekday to finish your work.

   THE LASER SOURCE SHOULD NEVER BE USED WITH THE SHUTTER OPEN. IT'S LIGHT IS FAR TOO INTENSE FOR THE PHOTOMULTIPLIER TUBE.

   These instructions will become clear when the apparatus is described.

2. The laser source is modest in power (5 mW). Nevertheless, do not shine it directly in your eye, and do not use the mirror provided when using the laser source. Use the mirror only with the bulb source.

3. There is an interference filter on the end of the bulb source. You will remove this filter for some of the procedures. Please keep your fingers off this filter.

4. There is a built in alarm that will sound if the shutter is opened while the laser is on or while the large channel lid is open. If you ever hear this alarm, immediately close the shutter and determine why the alarm sounded.

1 Wave-Particle Duality

Is light a wave or a particle? The Dutch physicist Christiann Huygens (1629-1695) advocated that light was a wave. Huygens' principle is often used to describe how waves in general propagate. In 1704 Newton published the first edition of his book *Optiks* in which he championed the notion that light consisted of particles which we now call photons. Thomas Young performed a two slit interference experiment in 1801. The dark bands observed by Young can only be explained by destructive interference, a wave, not a particle, property. Maxwell's equations, with their wave solutions, also supports a wave theory for light. On the other hand in the early 20th century there were phenomena involving light that could only be explained by a particle theory. Examples are the photoelectric and Compton effects. Is light a wave or a particle? It is both, but not at the same time. Whether the particle or wave description is used depends on what question is being asked. Questions about the propagation of light require wave theory. Some questions about the interaction of light with matter require the particle theory. This is commonly called wave-particle duality. There is nothing in our macroscopic world that corresponds to this duality.

You have seen two slit interference patterns, and may well have observed them in a lab. The interference pattern can only be explained by a wave theory. This experiment is a really good two slit interference experiment with slits that can be controlled by micrometers screws. The positions of the maxima and minima can be determined quite precisely, and one or the other of the two slits can be blocked off. When you block off one slit there are detector positions where the light intensity actually increases!

In this apparatus there are two light sources and two detectors of light intensity. By far the stronger source is a laser diode. For use with this source a photodiode detector is used. This source and detector are very useful for aligning the apparatus and easily getting good diffraction patterns.

The other source is an incandescent light bulb equipped with a narrow band interference filter. This source is operated at such low power that it is necessary to use a PMT as a detector. It is possible to reduce the intensity of the light so that in the apparatus there is at best one photon in transit at any given time. Nevertheless, if at this low intensity enough time is taken to measure the interference pattern the same results for the interference pattern are obtained as when higher intensities are used and many photons are in the apparatus at the same time. How is it possible that an interference pattern is produced when there is at best only one photon in the apparatus at one time?

Using somewhat the same train of thought, at these low intensities is it possible to ask which slit a photon went through? The answer is no if you wish to keep the usual two slit interference pattern. Any measurement sensitive enough to tell you which slit the photon went through destroys the two slit interference pattern. Read Feynman!

2 Theory

Consider a monochromatic plane wave incident normally on two parallel slits each of width a and with a distance between their centers of d. Let θ be the angle between the normal to the plane of the slits and the direction of observation. The intensity $I(\theta)$ is given by

$$I = I_0 \cos^2[\pi d \sin\theta/\lambda] \left(\frac{\sin[\pi a \sin\theta/\lambda]}{\pi a \sin\theta/\lambda} \right)^2, \tag{1}$$

where I_0 is the intensity in the forward direction ($\theta = 0$) and λ is the wavelength of the light. For what values of θ is the intensity I is the intensity zero? You may assume that the pattern is observed on a screen so distant from the two slits that the far field or Fraunhofer condition applies. Also the small angle approximation may be used. If L is the distance from the double slit to the screen and y is the distance on the screen from the center of the pattern ($\theta = 0$) to another point on the pattern given by θ, then $\theta \cong \sin\theta \cong \tan\theta \cong y/L$.

In this equation, the $\sin^2$ factor is the diffraction pattern of a slit of width a. The $\cos^2$ factor is the interference pattern of two very narrow slits whose separation between centers is d. The $\sin^2$ factor can be thought of as modulating the $\cos^2$ factor. As $d > a$, the spatial oscillations of the $\cos^2$ factor are more rapid than for the $\sin^2$ factor. Fig. 1 shows the intensity for $d = 4a$.

3 The Apparatus

See Fig 2. The apparatus consists partly of a *long* box (120.7 cm) with a square cross section (5.7×5.7 cm). There are two micrometer screws coming out of this box which move slits inside the box. It is assumed that you are viewing this box and the apparatus from the side which has these micrometer screws sticking out. Attached to the right end of the long box is a flange to which is attached the detector box. The detector box should not be opened. Inside the detector box are a photomultiplier tube (PMT), a power supply for the PMT, and two amplifiers. At the top of the flange is a rod with a cable coming out the end. This rod operates a shutter that seals off the detector box from light and protects the PMT when it is not in use. The shutter has a large area photodiode mounted on it. When the rod is down the PMT is protected and the photodiode is in position to detect the fringe patterns in the apparatus. The signal from the photodiode is carried on the cable from the shutter rod. When the rod is up, the photodiode is removed from the light path and the PMT is exposed.

Both the long box and the detector box are light tight, but the long box has a cover that is removable. You should find the cover in place and held by 4 "L" latches. At this point please be sure that

- the cover is latched in place, and that
- the power cord to the apparatus is unplugged from the line. This will assure that no sources are on and no voltage is being supplied to the PMT. The power cord goes to a small box made by Astrodyne which supplies 15 V DC to the apparatus.

Now move the shutter rod up and down a few times to get a feel for its operation. Leave the rod in the <u>down</u> position (shutter closed) to protect the PMT.

Remove the cover, proceeding as follows. Lift each L latch up and rotate it 90 deg. The right end of the cover is under the flange and the cover must be slid left a few cm in order to remove the cover. The cover has a channel around its edge, so as to slide the cover left it is necessary to lift the left end of the cover about 1 cm before sliding the cover left. Remove the cover and and lay it on its back in a safe place where it will not get knocked onto the floor.

In what follows, you will be asked to gain some familiarity with the knobs and switches of this apparatus. It is suggested that you operate these controls, which will be OK AS LONG AS THE AC POWER TO THE APPARATUS IS STILL UNPLUGGED. PLEASE CHECK AGAIN THAT THIS IS SO. When you are through experimenting with the controls, leave all switches off and all potentiometers fully counter clockwise (CCW) so that when power *is* supplied to the apparatus no voltages will be immediately applied.

On the side of the detector box is the *detector* panel. This panel is divided into 5 areas.

1. Photodiode- There are two BNC connectors. The one marked INPUT should be connected to the cable from the shutter rod. When the photodiode is being used, the OUTPUT should be connected to the (Fluke) multimeter by a cable which has a BNC connector on one end and a double banana plug on the other end.

2. High Voltage- There is an off-on switch which turns the power to the PMT high voltage supply on and off. A 10 turn potentiometer adjusts the voltage. The numbers on the potentiometer are not a good measure of the voltage. When the PMT is being used, the two monitor jacks should be connected to the multimeter in the DC volts mode. The PMT voltage is about the multimeter voltage times 1000. Reasonable PMT voltages begin at around 540 V, or a multimeter DC voltage of 0.54 V.

3. Photomultiplier- When the PMT is being used, the OUTPUT BNC should be connected to channel 1 of the scope. This output is actually not the last dynode of the PMT. It is the output of a charge sensitive pulse amplifier whose input is the PMT. The SMA connector marked INPUT TEST PULSE allows a test pulse to be applied to the input of the amplifier. Leave the cover on this connector.

4. Discriminator- The BNC marked OUTPUT TTL (transistor-transistor Logic) should be connected either to channel 2 of the scope or to channel A of the counter. When the discriminator LEVEL potentiometer is properly adjusted, a TTL pulse is delivered for each pulse delivered by the PMT. Each of the TTL pulses is a rectangular pulse with one level at ground, the other level at about 4 V, and a duration of about 300 ns.

5. DC Power- Power is provided to the detector box by the connector attached to this panel. The power comes from the other end of the apparatus.

Facing you at the left end of the long box is the *source* panel. This contains the following items.

- Source Switch- This 3 position switch turns the laser on, the bulb source on, or turns both sources off.

- Bulb Power- This potentiometer adjusts the power to the bulb source when when the source switch is on bulb.

- Laser Mod Input- Allows modulation of the laser source.
- DC Output- Supplies power to the detector box.
- DC Input- Input power for the apparatus supplied by the Astrodyne power supply.
- Alarm- Goes off if power is being supplied to the apparatus and you are doing something that is not good for the PMT.

Looking inside the long box, at the left end are the electronics for the sources. The electronics are separated from the rest of the long box by a solid light baffle. There are also two other light baffles inside the long box which you should identify. These baffles have half inch diameter circular holes to allow the light to travel through the apparatus. The light baffles are easily identified as they have black foam on their tops. As you would expect, most of the apparatus is black so as to reduce reflected light. Avoid scratching the black surface.

To the right of the electronics are the two light sources. First is the laser source, a black box whose position can be adjusted by two brass screws outside the long box and a white nylon screw inside the long box. The laser box can be translated horizontally by rotating the brass screws in the same sense, and can be twisted by rotating the screws in opposite senses. The laser beam can be rotated in the vertical plane by using the white nylon screw. Plug in the power cord for the apparatus and turn on the laser source. The manufacturer states that the wavelength is $670 \pm 5\ nm$. Observe the laser beam and turn the laser off.

To the right of the laser source is the bulb source, a cylindrical tube attached at its left end by a spring tensioned Allen head screw. At the right end of the bulb source is a somewhat larger diameter cylinder which has an interference filter in its right end. This filter passes light in the range 541 to 551 nm. This light appears green. Take care to keep your fingers off the interference filter. The bulb source is easily moved up and down when the screw that supports the right end is all the way to the bottom of the long box. This screw is accessed below the bottom of the long box. The bulb source also pivots in a vertical plane about its left end. With the supporting screw all the way to the bottom of the long box, practice moving the bulb source up and down. When the bulb source is being used it is in the up position. To use the laser source the bulb source is pushed all the way to the bottom of the long box and the laser beam travels just above the bulb source. Moving the bulb source up is facilitated by using the short end of an Allen wrench on the silvery bracket holding the left end of the bulb source. There should be an Allen wrench on the bench. Hook the Allen wrench on the right side of the slivery bracket so as not to disturb the position of the diode laser. Try pushing the bulb source all the way to the bottom of the box so that the larger diameter filter (not the smaller diameter cylinder) is fully flush with the bottom of the long box. Turn on the laser and see if it clears the filter. Do not use the mirror to observe the laser beam. Observing the laser beam can be done with a card or a Teach Spin “T” card. Try removing the interference filter at this time. First swing the right end of the bulb source up by about 30 deg and remove the interference filter by twisting and pulling. Set the filter down so that it will not roll off the table. Checking that the potentiometer for the bulb source is fully CCW (set to 0) turn on the bulb source and advance the potentiometer so that you can see the bulb source illuminate. Do not exceed a reading of about 6 on the potentiometer so as to preserve the life of the bulb. Bulb life is also enhanced by turning the potentiometer to 0 before turning the bulb source off with the switch. Turn the bulb source off and replace the filter.

There are 4 slits in the apparatus, all aligned vertically. From left to right they are "source", "double", "blocker", and "detector." Each of these is cut in a thin metal foil which is attached to a thicker rectangular piece of metal. We shall refer to these slit assemblies as "slits." The word slit shall mean, depending on context, either

- the slit itself, or
- the rectangular piece of metal to which the foil with the slit in it is attached.

The slits are held magnetically to holders which stick up vertically from rectangular blocks sitting on the bottom of the long box. See Fig. 3, and note that one of the holders in the apparatus is "turned around." The slits fasten to the side of holders which have the least distance to the edge of the blocks. (They won't stick to the other side as that side does not have the magnet.) Either side of the slits will stick to the magnetized holder but they will stick better if the foil is away from the holder.

- Source slit- When using the bulb source, which is an incoherent source, this slit is necessary to illuminate the double slits with light that is coherent enough to produce an interference pattern. This slit is not necessary with the laser source but for convenience is left in.
- Double slit- These are the slits which produce the interference pattern.
- Blocker slit- The blocker slit can be moved by the left micrometer drive. The opening is more like a rectangular aperture than a slit. It is mounted close to and to the right of the double slit. To observe a two slit interference pattern, both edges of the blocker slit are far from the light beam. The blocker slit can be moved to block light from either slit of the double slit so as to produce a single slit interference pattern, and it can be used to block the light from both slits.
- Detector slit- This slit is mounted on the second micrometer drive and is located just left of the flange. This slit scans the interference pattern. It is assumed that the large area photodiode and the first photo-sensitive dynode of the PMT have constant sensitivities over their surfaces.

4 Aligning the Apparatus

The shutter must remain closed for this part of the experiment.

Remove the cover. Remove the slits from the apparatus, remembering which slit goes where. Handle the slits gently by the edges. The slits can be slid in their mounts by using fingers and a tooth pick on the edges of the slits. The procedures for alignment follow.

1. The alignment jig is a T shaped piece of clear plastic that has scratches on one face. The jig rests on the two edges of the long box. The jig has a vertical scratch which is the horizontal center of the apparatus, and 3 horizontal scratches the center one being the vertical center of the apparatus. The vertical scratch and the center horizontal scratch are the "cross-hairs." Turn on the laser, and place the alignment jig just to the left of the source slit holder so the scratches face the laser beam. Adjust the laser box so that the laser beam hits the center of the cross-hairs. Adjusting the laser box is facilitated

by pressing lightly down on the top of the laser box with a finger so as to eliminate some of the slop in the adjusting mechanism.

2. Remove the jig and put a T card between the double and blocker slit holders. Note that the laser beam has diffracted to about a 1 cm disk. Check that the laser beam is reasonably well centered. If it is not, it will be necessary to move the laser box horizontally one way or the other and then to center it again on the jig when the jig is inserted just to the left of the source slit. You may have to do this several times to converge on good alignment. Note that you cannot move the laser box up and down, but that you can point the laser beam up and down.

3. Remove the jig from the long box and place the T card in the vacinity of the detector slit holder. Check that the laser disk is reasonably well centered.

4. Put the source slit into its holder and push it down so that its bottom edge makes full contact with the holder block. If you have to move this slit sideways, maintain that full contact.

5. Drop a T card between the double and blocker slit holders and move the source slit sideways so that the single slit diffraction pattern is centered as observed on the T card.

6. Use the T card to check that the single slit diffraction pattern is centered in the area of the detector slit holder.

7. Put the double slit in its holder and bottom it. Move the double slit sideways so that the double slit is centered in the single slit diffraction of the source slit. A nice way of doing this is to put the T card just to the right of the double slit and use the magnifying glass to observe the double slit from the left with the magnifying glass. You will see the reflection of the double slit in the single slit diffraction pattern and can easily move the double slit so that it is centered in the diffraction pattern.

8. Center the blocker slit in its holder, bottom it, and put the T card a cm or two to the right of the blocker slit. Observing the T card with magnifying glass, move the blocker slit so that it starts to cut off one of the two slit images. You will find that the vertical edge of the blocker slit is not completely parallel to the double slit image. Using tooth pick and fingers, rotate the blocker slit so that its vertical edge is parallel to the image of the double slit. This is a bit tricky, and requires making a number of small adjustments to the orientation of the blocker slit and checking by moving the blocker slit with the micrometer drive.

9. Be sure you understand how to read the micrometers. There is an explanation in appendix A.

10. Determine the following micrometer readings. A reading in which the double slit images are centered in the blocker slit opening. This will be the position of the blocker slit for observing the two slit interference pattern.

    A reading in which one slit image is blocked, and a reading in which the other slit image is blocked. For these two, it is important that one slit image is fully passed, and the other is fully blocked. For these positions of the blocker slit the single slit interference patterns will be observed.

A reading for which both slits are blocked by one side of the blocker slit, and a reading for which both slits are blocked by the other side of the blocker slit. These positions will be used to determine background signal.

11. Insert the detector slit in its holder and bottom it.

12. Put the T card just to the right of the detector slit, and using the magnifying glass, observe the detector's slit reflection against a maximum of the two slit interference patter. This will require a darkened room and some care. Rotate the detector slit if necessary to align it with the interference pattern.

The apparatus should now be in good alignment. How good a job you did will be reflected in the quality of the two slit interference patterns you observe.

5 Experiment Using Laser Source

The shutter must still remain closed for this part of the experiment.

In this scetion, the two slit interference pattern is examined using the laser source and the photodiode detector. The signal to noise ratio is high and there are lots of photons in the apparatus at any given instant of time. Due to the precision of the apparatus and blocker slit, a number of interesting phenomena can be observed.

Adjust the position of the blocker slit so that the light from both slits is passed. Without disturbing the laser, be sure the bulb source is out of the way and at the bottom of the long box. Put the cover on the long box and latch it. The shutter rod should be down, and its cable connected to the photodiode INPUT connector. Connect the photodiode OUTPUT connector to the Fluke multimeter using the cable with a BNC connector on one end and two banana plugs on the other end. Set the Fluke to DC voltage and turn the laser on. Scan the detector slit using the micrometer screw and observe the photodiode voltage. At the peaks in the pattern you should see 0.5 V or more on the Fluke. If the apparatus alignment is really good, you might see 2.4 V on the Fluke. Momentarily turn the laser off and record a background voltage reading. This should be subtracted from your voltage readings with the laser on.

Scan the two slit interference pattern by moving the detector slit with the micrometer screw. At each position of the detector slit that you choose, record the Fluke voltage. Start by measuring the intensity at all maximums and minimums out to the second minimums on either side of the peak of the single slit pattern. If you have time later you can fill in some extra points. Take some background readings by blocking both slits and subtract the background from your data. Plot your results with position on the x-axis and intensity on the y-axis.

Move the blocker slit so that the light from only one slit is passed, and scan the pattern out to the second minimum. Use your judgment as to where to make measurements. Subtract background from your data. Plot these results. Repeat for light from the other slit.

Examine your plots and answer the following questions.

1. What is the ratio of the maximum intensity for the two slit pattern to the maximum intensity for the one slit pattern? Can you explain your result?

2. You should find positions of the detector slit for which the intensity of the two slit pattern is less than that for the one slit pattern. As less light is being transmitted in the latter case, how do you explain this?

3. What is the separation between between the two slits?

PLEASE REREAD PRECAUTIONS ON PAGE 1

6 Experiment Using Bulb Source- Single Photon Interference

You will open the shutter in this part of the experiment. Right now it should be closed and remain closed until later in the section when you are told (in bold text) that you can open it.

For this section it is important that the positions of the slits and of the laser source are not changed. You should also know the detector position that gives maximum intensity of the two slit pattern and the positions of the blocker slit that give the two slit pattern, the two one slit patterns, and no pattern (both slits blocked).

Set the blocker slit to give the two slit pattern and set the detector slit to give the maximum of the two slit pattern.

Using the laser source you should have obtained very respectable two and one slit patterns. If you have not, you should realign the apparatus and try again. The signal to noise ratio using the bulb source is much less than when using the laser source. The main point in using the bulb source and the PMT is that the light intensity can be reduced to a point where there no more than one photon in the apparatus at a given instant of time, yet an interference pattern is observed. This is a more difficult way of doing the experiment but there are important *conceptual* advantages.

Remove the cover of the long box. In the following procedures avoid moving the laser source. Tip up the right end of the bulb source and remove the interference filter. Turn on the laser source and using the short end of the Allen wrench on the silver bracket holding the left end of the bulb source, and also using your fingers, raise the bulb source so that the laser beam hits the middle of the Allen head screw. The bulb source should be horizontal. Turn the screw on the bottom of the long box to raise the support for the bulb source and make it more stable. Turn off the laser.

Check the alignment of the bulb source as follows. Turn on the bulb source to a setting of 5. Inserting the mirror in the long box check for white light at the following locations: left and right of the source slit, right of the blocker slit, and left of the detector slit. If the white light intensity seems reasonable, turn the potentiometer to zero and switch off the bulb source. Disturbing the position of the bulb source as little as possible, put the interference filter back on the bulb source and put the cover back on the long box. Latch the cover.

You will want to measure the high voltage to the PMT. On the detector panel, move the BNC connector attached to the photodiode OUTPUT terminal to the high voltage MONITOR terminal. Leave the other end of the cable connected to the Fluke. (Leave the photodiode INPUT connector in place.)

The pulses from the PMT and discriminator are monitored using a Tektronix TDS1002 scope. This is a fast (60 MHz) two channel (CH1 and CH2) digital oscilloscope. While you will have a manual for this scope enough information for its use may be provided here. For further questions see the manual. The trace of the voltages being observed appear on the screen or *display*. Some of the most important parameters about the status of the scope, such as vertical sensitivity, sweep speed, trigger levels, and trigger conditions, appear on the borders of the display and not on the knobs controlling these parameters. See Fig. 4 for a picture of the display along with the following text for descriptions of the various words and symbols that appear on the display. There is always a menu on the right side of the display. A particular menu can be called for by pushing one of the menu buttons. To the right of the display are five unmarked buttons which are used to choose from the menu. The triggering functions you will need are controlled by 3 buttons on the upper right of the scope face. These 3 buttons are:

- AUTOSET- Chooses scope parameters that will give you a stable waveform. DO NOT USE THIS BUTTON. You will be given suitable scope parameters, and using this button will change them.

- RUN/STOP- This is the default and is the proper choice for much of this experiment. In the RUN mode the scope accumulates data up to the trigger point, and then when a trigger condition occurs, accumulates data past the trigger point. After a trigger, the trace is briefly displayed and then the scope waits for the next trigger. This is a storage scope. Unlike an analogue scope, it is possible to display some of the waveform that occurs before the trigger. A good position for the horizontal position arrow (See Fig. 4, item 4) is right in the middle which is taken as zero time. (The M stands for Main Time Base.)

  In the STOP mode (the RUN/STOP button toggles) the last triggered trace is held and displayed. If there are a lot of pulses which are not all the same, this enables a single pulse to be carefully examined.

- SINGLE SEQ- When pushed, a single triggered trace is displayed. In function, this is similar to the STOP mode. You should try this mode, but for general monitoring go back to the RUN mode.

Turn on the scope using the toggling button on the top and wait 30 s for the self checks to be completed.

- Press the DEFAULT SETUP button. This will assure that many of the parameters will be as you want them. For example, it will choose CH1 as the trigger source.

- Press the CH1 menu button and choose 1X for the PROBE. You will not be using an attenuating probe and do not want the scope to compensate for such attenuation.

- Press the CH2 menu button. As the default setup does not activate CH2, this will do so. Again, set PROBE at 1X. The traces for CH1 and CH2 will overlap. Move the CH2 trace down toward the bottom of the display as it will be overlapping the CH1 trace.

- Set the CH1 vertical sensitivity at 50 mV/Div, the CH2 vertical sensitivity at 2 V/Div, the sweep speed at 250 ns/Div, and the trigger threshold to 20 mV.

- If you are going to be returning to this experiment, you can wait 3 s after making any adjustments to the scope before turning the scope off. Your settings will be preserved for when you next turn on the scope and you will not have to readjust the scope.

The PMT pulses are short (∼250 / ns) and proper impedance matching is necessary to avoid reflections. Check that 50 Ω BNC shunts are connected to both the CH1 and CH2 inputs to the scope and to the channel A input of the counter. Connect the PMT OUTPUT to CH1 and the discriminator OUTPUT to CH2 using cables with BNC connectors.

Check that the shutter is closed, and the potentiometers for the bulb source, high voltage, and discriminator are set at zero. Plug in the astrodyne power supply and then turn the laser-off-bulb switch to bulb. (This is the only position for which the high voltage supply for the PMT will work.) Turn the Fluke to DC volts. Turn the High Voltage switch to On and slowly turn the high voltage potentiometer clockwise. Monitor the scope while you do this, and if at any time there is there a flood of pulses, turn the high voltage to zero and look for a light leak. Monitoring the PMT voltage on the Fluke, set the Fluke reading to 0.6 V which will be a PMT voltage of 600 V. At a PMT voltage of 550-600 V you should see a background pulse from the PMT every few seconds. If you do not, check the scope parameters and if necessary check with your instructor.

Assuming that you are seeing a few background pulses, press the RUN/STOP button to capture a pulse. There are two amplifiers in the detector unit. The PMT directly feeds a charge sensitive amplifier whose output appears on CH1. The charge sensitive amplifier feeds another amplifier whose output is a rectangular TTL (transistor transistor logic) pulse which has a height of about 4 V and a width of about 300 ns. This TTL pulse appears on CH2. For low level pulses there may not be a TTL pulse, but with a trigger level of 20 mV there will most likely be a TTL pulse with each PMT pulse. There is coupling between these two amplifiers, and you will see the effect of the sharp edges of the TTL pulses on the PMT pulses. The discriminator potentiometer is actually a gain control. This will be set shortly. Return to continuously monitoring the pulses by pushing the RUN/STOP button again.

In what follows, it is assumed that the blocker slit is adjusted to pass the light from both slits, and that the detector slit is centered on the interference pattern (maximum intensity). **You may now open the shutter**. Do not open the lid or switch to the laser light until you close the shutter (you will not need to do either for the rest of the experiment). With no light leaks and the bulb potentiometer at zero there should be no significant increase in pulse arrival rate. Slowly turn the bulb potentiometer up to 2. You should see an increase in pulse rate on the scope. Disconnect the CH2 cable from the scope and connect it to the channel A input to the counter. Turn the counter on, set the counter GATE to 1.0 s and the leave the FUNC setting at default, which is FREQ/CHA. Increase the bulb brightness so that you get a pulse rate of around 0.5 kHz. The bulb potentiometer might be between 3 and 4, depending on how well the apparatus is aligned. Turn the discriminator potentiometer up enough so that the count rate plateaus, which is at a value of about 2. (The discriminator is actually a gain control which boosts the pulse height enough so that most pulses pass through a genuine discriminator.) Adjust the bulb intensity to give a count rate of around 1.0 kHz.

The arrival of the pulses is random. Check out the statistics as follows. Using the HOLD button on the counter (which toggles) measure the number of counts in ten 1 s intervals (this is the gate time). Average these counts and calculate the standard deviation σ. Are you satisfied that most of your counts lie in the range of the average $\pm\sigma$?

Measure the two slit interference pattern intensity every 0.10 mm for about 2 mm on each side of the maximum. At each location it is enough to make one 1 s measurement, noting the statistical uncertainty in your data. Measure the pattern for each slit by itself, using the blocker slit to cover one slit at a time. Now make some background measurements by covering both slits with the blocker slits, first moving the blocker slit in from one side and then the other side.

Set the blocker slit to pass the light from both slits. Turn the bulb potentiometer down to zero and connect the cable carrying the TTL pulses to the "cricket." The cricket will give a click for every pulse, and is an interesting way of getting a feel for random events. Turn the bulb source up a bit to see how this goes for somewhat higher pulse rates.

Turn both potentiometers to zero, set the switches at off, **and close the shutter**. Turn off the Fluke, scope, and counter. Unplug the power supply.

Subtract the background from your data and on the same graph plot your 3 intensity distributions (two slit and two one slit). Intensity should be on the vertical axis and detector position on the horizontal axis. Answer the following questions.

1. For the green photons used in this part of the experiment the PMT produces a pulse about 4% of the time. Calculate the average time between photons and the time one photon spends in traveling between the source and detector slits. Is there likely to be more than one photon in the apparatus at any given time? If not, how is it possible that a two slit interference pattern is produced? Does it make any sense to ask which slit the photon goes through?

2. Are there regions where the one slit pattern is more intense than the two slit pattern? Discuss.

3. How does the two slit pattern differ from the one you obtained using the laser? Why?

4. What is the distance between the centers of your two slits? What is the width of each slit?

7 Finishing Up

Please leave the bench as you found it. Thank you.

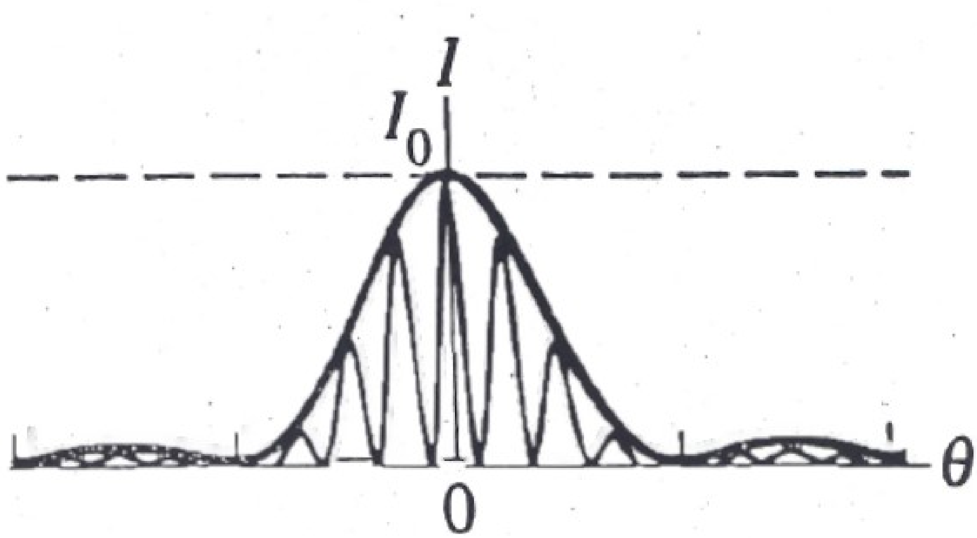


Figure 1:

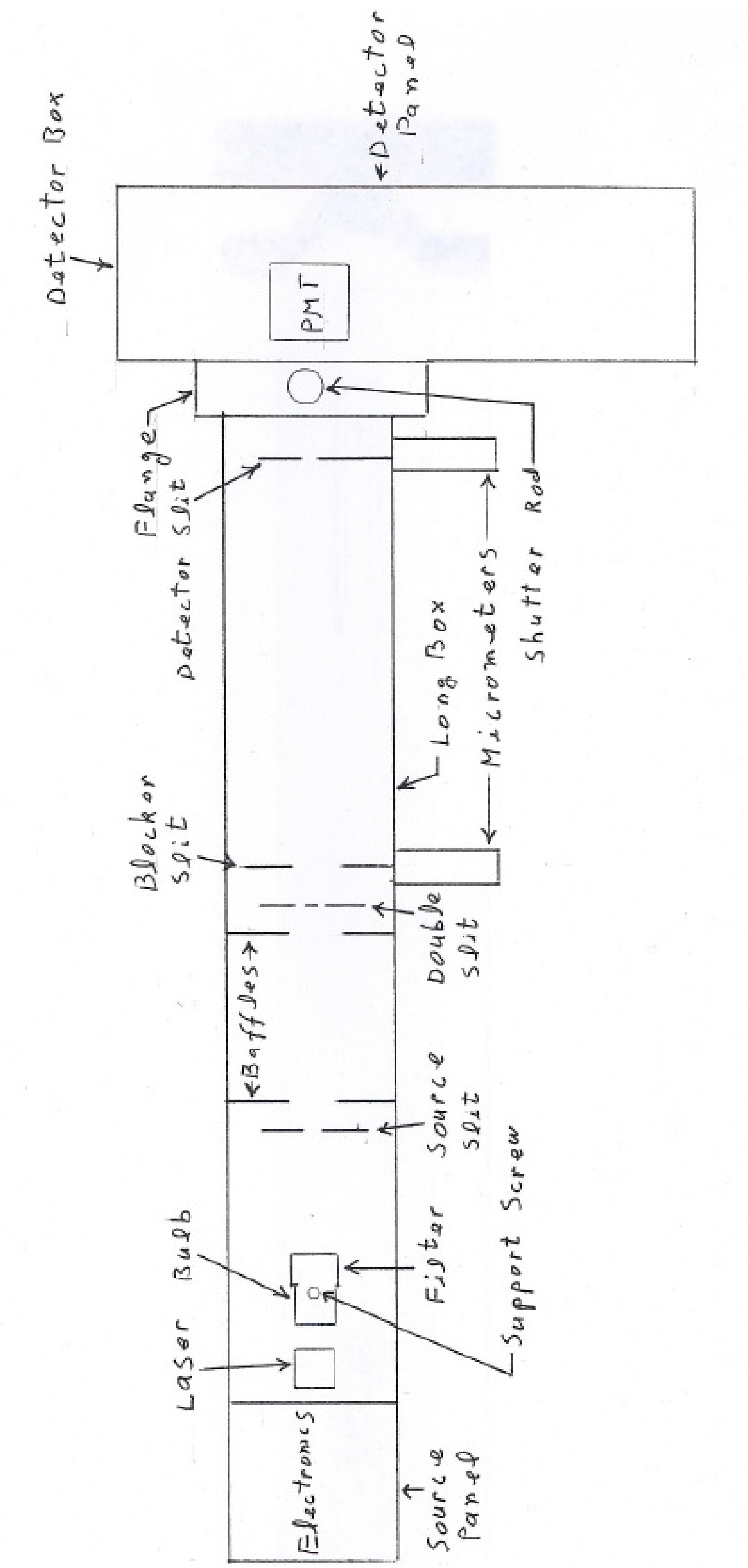


Figure 2: Not to scale.

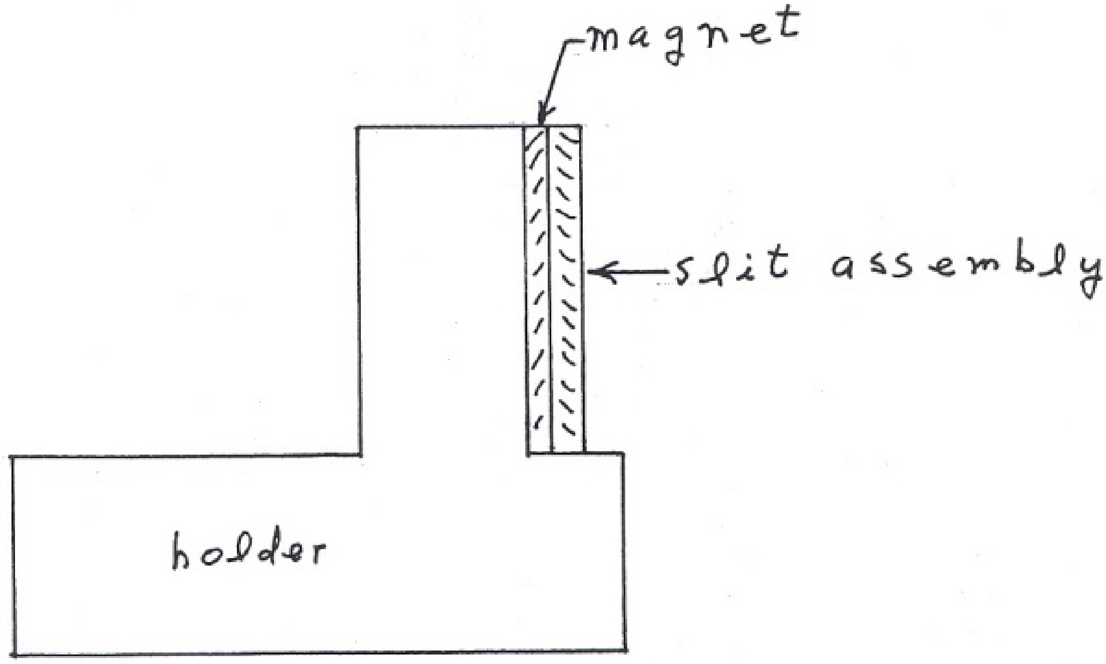
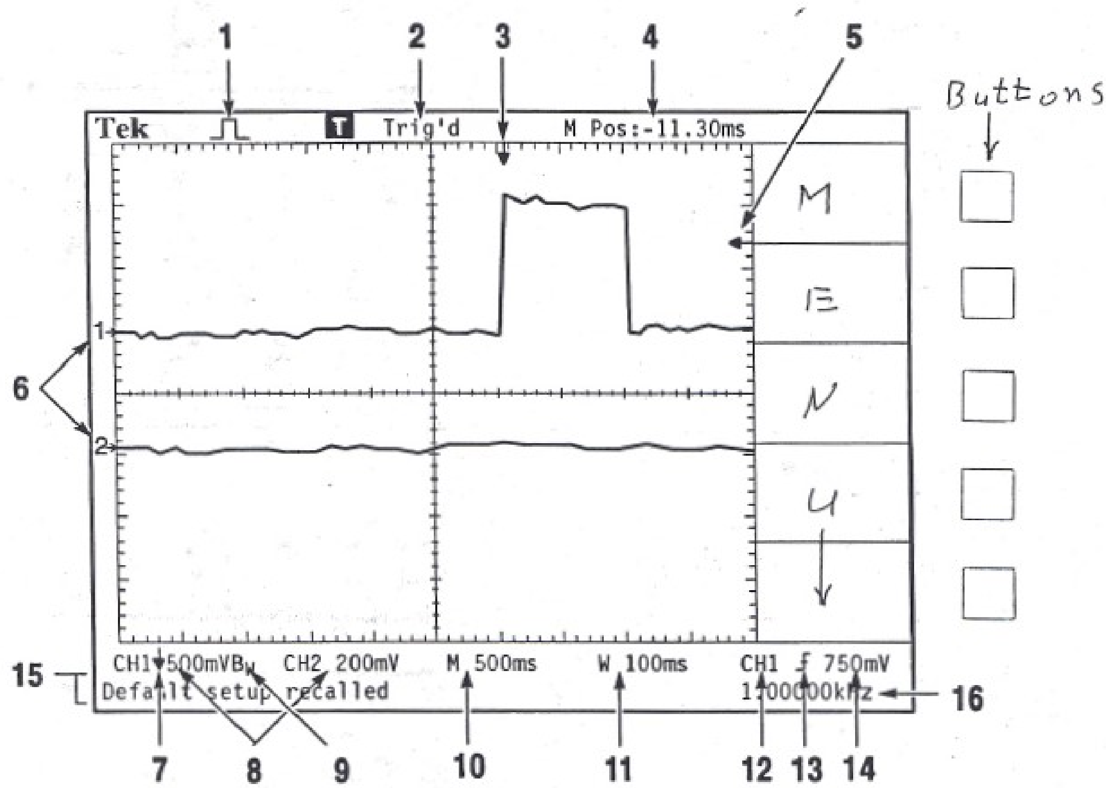


Figure 3:

Display Area

In addition to displaying waveforms, the display is filled with many details about the waveform and the oscilloscope control settings.

***NOTE**. For similar details for the FFT function, refer to page 119.*



1. Icon display shows acquisition mode.

 Sample mode

 Peak detect mode

 Average mode

2. Trigger status indicates the following:

☐ Armed. The oscilloscope is acquiring pretrigger data. All triggers are ignored in this state.

[R] Ready. All pretrigger data has been acquired and the oscilloscope is ready to accept a trigger.

[T] Trig'd. The oscilloscope has seen a trigger and is acquiring the posttrigger data.

● Stop. The oscilloscope has stopped acquiring waveform data.

● Acq. Complete. The oscilloscope has completed a Single Sequence acquisition.

[R] Auto. The oscilloscope is in auto mode and is acquiring waveforms in the absence of triggers.

☐ Scan. The oscilloscope is acquiring and displaying waveform data continuously in scan mode.

3. Marker shows horizontal trigger position. Turn the HORIZONTAL POSITION knob to adjust the position of the marker.

4. Readout shows the time at the center graticule. The trigger time is zero.

5. Marker shows Edge or Pulse Width trigger level.

6. On-screen markers show the ground reference points of the displayed waveforms. If there is no marker, the channel is not displayed.

7. An arrow icon indicates that the waveform is inverted.

8. Readouts show the vertical scale factors of the channels.

9. A B_W icon indicates that the channel is bandwidth limited.

10. Readout shows main time base setting.

11. Readout shows window time base setting if it is in use.

12. Readout shows trigger source used for triggering.

13. Icon shows selected trigger type as follows:

- Edge trigger for the rising edge.
- Edge trigger for the falling edge.
- Video trigger for line sync.
- Video trigger for field sync.
- Pulse Width trigger, positive polarity.
- Pulse Width trigger, negative polarity.

14. Readout shows Edge or Pulse Width trigger level.

15. Display area shows helpful messages; some messages display for only three seconds.

If you recall a saved waveform, readout shows information about the reference waveform, such as `RefA 1.00V 500μs`.

16. Readout shows trigger frequency.

Message Area

The oscilloscope displays a message area (item number 15 in the previous figure) at the bottom of the screen that conveys the following types of helpful information:

- Directions to access another menu, such as when you push the TRIG MENU button:

  `For TRIGGER HOLDOFF, go to HORIZONTAL Menu`

- Suggestion of what you might want to do next, such as when you push the MEASURE button:

  `Push an option button to change its measurement`

- Information about the action the oscilloscope performed, such as when you push the DEFAULT SETUP button:

  `Default setup recalled`

- Information about the waveform, such as when you push the AUTOSET button:

  `Square wave or pulse detected on CH1`

Appendix A. How to Read a Micrometer Drive

Two micrometer screws allow precise mechanical adjustments to the positions of the slit-blocker and the detector slit in this apparatus, and you should learn how they work, and how to read their scales. The two micrometers, and the mechanical flexture mounts they drive, are identical.

Each micrometer consists of a very carefully made metric screw thread of pitch exactly 0.50 mm, so that the rotating shaft of the micrometer advances 0.50 mm for each full (clockwise) turn of the screw. The markings on the micrometer are in place so you can

- keep track of the number of turns you've made, and thereby read the position of the shaft's working end to the nearest 0.50 mm; and
- interpolate within a full turn, so that you can finally quote the position of the shaft's working end to the nearest 0.01 mm .

Here's how to read the number of turns. Call the fixed part of the micrometer the 'barrel', and the rotating external part the 'drum'. Note that on the barrel there is a printed longitudinal 'stem', along which there are 'branches' emerging alternately on either side. On the one side, every fifth mark is labelled with an integer, 0, 5, 10, and so on: these are at 5-mm spacing, and between them are the 1-mm marks. On the other side of the stem are also branches at 1-mm spacing, but these lie halfway between the mm-marks, and form the 'half-mm' marks. Now turn the drum until the 0-mark on its circumference lies right along the line of the stem (this marks the 0° point on one of its 360° rotations). Find the last branch exposed to view on the barrel, and use it to read the micrometer to the nearest 0.50 mm.

For example, if the 5-branch and the next branch on the other side of the stem, are the last exposed to view, the micrometer is set to 5.50 mm.

Now from that position, further counter-clockwise rotation of the drum will withdraw the screw, by another 0.50 mm for a full turn. If you rotate by a fraction N/50 of a full turn, you'll withdraw the micrometer by (N/50) x 0.50 mm, or (0.01 x N) mm. The drum's periphery is conveniently printed with 50 marks around the circumference, and every fifth one of these is labelled, so that you can read the integer N directly. This provides the rest of the information you need to read the micrometer to 0.01 mm.