PHYSICS 410/510

EXPERIMENT 0-14

THE VELOCITY OF LIGHT

Align the optics and, for various rates of rotation of the small mirror, observe the deflection of the slit image from its zero position (which is perhaps best obtained at very low rates of rotation), the light traversing the path provided by optics.

Set the deflections to successive 1/2 mm positions from zero up to the maximum {this can be done pretty precisely) and measure the speed of rotation of the mirror. This may be done by reflecting an auxiliary light from the mirror onto a photocell and taking its output into the vertical system of an oscilloscope with the variable frequency oscillator being fed into the horizontal system. Calibrate the latter against the standard 60 cycle frequency source and then calculate c. It is easier to feed the photocell signal into a frequency counter and get rotation speed directly.

A more sophisticated method of proceeding is to image the slit with the returned light onto another slit. The light through it is rendered parallel and put directly into a telescope at the back end of which is a photomultiplier. (This combination is also used in the next part of the experiment.) One maximizes the signal in the case of the slit single image or minimizes it if the double image is used. By translating the source slit transversely {and measuring the displacement to obtain c) one obtains the same signal under mirror rotation as with no rotation. The mirror frequency can be obtained with the same signal. Somewhat better results are obtained this way, but there is something lost by not seeing the image move over as the mirror speeds up. Thus, the visual method is used first. The frequency counter can again be used as above.

For the more advanced student another approach will also be used. The source optics is turned around and the distant mirror moved to the far end of the corridor. The source is imaged first in the Kerr Cell {with the external polarizers removed during the adjustment), making certain that the light beam misses the condenser plates in the cell. With the long focus lens {that is used above along with the telescope-photomultiplier combination) image this image on the distant mirror. Using the corner reflector in front of the telescope-photomultiplier lens, the distant mirror is adjusted so that the corner reflector flashes bright. This makes it possible to know at the far mirror that it is returning light to the telescope lens. The two beam splitters are arranged to feed light via the short path into the telescope lens and the diaphragm adjusted to approximately equalize the two intensities. With the blocked Kerr Cell now being pulsed with a high voltage, two pulses will be observed on the oscilloscope with fast sweep. The time difference enables c to be roughly obtained. If the signal is fed into the radio receiver, noise is heard (the VTVM also indicates) which is minimized for certain frequencies to which the receiver is tuned. c comes from these data and the distance. If possible it would be worthwhile for the student to calibrate the receiver and the oscilloscope sweep speed against WWV and the frequency meter.

REFERENCES:

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Rotating Mirror -Visual

The apparatus as originally designed (and purchased from) by Leybold reflected a light beam from a rotating mirror through a simple long focal length lens to a plane mirror and thence back to the rotating mirror. A beam splitter in the path of the incident light deflected the return beam out where the displacement could be measured on a scale with eyepiece. At highest rotational speeds the deflection of the image of the slit, which is set at the object point for the long focus lens, is a little more than 3 mm if the overall object distance is 2f (so the image distance is also 2f, the image lying on the plane mirror); the image quality s not too good and shows chromatic aberration; the duty cycle is reduced through the use of only a plane return mirror; the plane mirror has been knocked off on the floor and now has a crack running across it; the aperture of the return mirror is about five inches and that of the lens about four.

t seemed that considerable improvement might be brought about by going to mirror optics throughout, except for the 1 1/2" lens used to focus the arc light spot on the rotating mirror. Thus the description will be made around the new reflecting optics. The return mirror is now a long radius sphere, 611 diameter and 47611 radius of curvature. Its center of curvature is to be at the main focusing mirror of 811 diameter and 57611 radius of curvature (f=241). The duty cycle is improved by the spherical return mirror; for any position of the beam on the main mirror, the return beam will fall incident object back on itself. This is not the case with the plane mirror except when the beam is exactly on-axis; an off-axis beam is deflected through the same angle still further off-axis. The mirrors suffer from one disadvantage; they should not be wiped or cleaned as readily. Thus, keep fingers, etc. off the mirror surfaces

Thus to align proceed as follows:

The starting point and reference zero for the distance measurements is a round headed screw sticking out at the right end from the shelf back of the experiment table. The object point will be pretty closely opposite this screw on the table when it is put in place after the optics are aligned. The light source and condensing lens mounted

bench is put at the right end of the table as close to the end as possible, directed at the motorized mirror on the small table at the left end of the alcove. The spherical return mirror is put at the left end of the experiment table, say 7811 from the reference screw. The rotating mirror is set on its sand bag 3 011 from the reference . The main mirror, if I have it worked out right, is set up against the north wall of the corridor on the small pedestal (with its edge braced against the wall) at a distance of 3311" from the reference screw. With the slit object opposite the reference screw these distances make a total object distance of 72911 , which with the 28811 focal length of the main mirror gives the required image distance of 476 II, the radius of curvature of the return mirror. Certainly close enough , for the image quality on the return mirror and after deflection by the beam splitter when it gets back is not bad.

To align the system in angle using a half silvered mirror as the splitter rather than the unsilvered slide.

Adjustments are now done with the exception of making the slit width what one likes and setting the scale zero to coincide with the zero position of the undeflected image. This may be done perhaps better than on the non-rotating mirror with the mirror rotating very slowly to give intermittent flashes of the image. The intensity is then down enough as to not make setting difficult as is the case when it is very bright.

The motor can now be turned up and the image will be much fainter and will be observed to move out from the zero position by an amount depending on the speed of rotation. At the highest RPr,1 the deflection is about 5.5 mm. It is suggested that the motor speeds be determined at every 1/2 mm position where by symmetry the dark space between the bright slit images can be set fairly closely, perhaps to 1 mm.

The mercury source is a high pressure arc very concentrated. It is started by switching on the DC the voltmeter will go off- scale so don't dawdle) and then touching the starter point with the Lepel spark coil. The light will go on, the voltage w drop and in a few minutes it will be up at high luminosity. The product of voltage and current should be about 00 watts. The lamp is supposed to stay on an hour or so after starting. Otherwise life is shortened for reasons I don't see. The motor speed is determined with the oscilloscope. One generates an electrical signal from the rotation of the mirror and puts it on a determined sweep. The sweep can be the internally generated linear calibrated sweep of the Tektronix, or it may be a signal from a calibrated oscillator, in which case one obtains stationary Lissajous patterns. If one uses the internal sweep, he makes the speed slow enough that he gets two or more pulses from the rotating mirror per sweep. If one doesn't believe the “dialed” sweep rate it can be calibrated using BC-221 frequency meter used later to also calibrate a radio receiver for the third part of the experiment. To generate a synchronous signal from the rotating mirror to get the speed, one uses an auxiliary incandescent source close to the mirror which is reflected twice each revolution into a closely spaced photocell (diode). It is gas filled so that with 90 volts across it and a 1 meg resistor in series with it a sizable signal is generated to put on the vertical deflection of the oscilloscope. This does increase the. background light seen while measuring image deflection singe twice in each revolution the rotating mirror directly reflects the source into the beam splitter. This also happens of course with the primary source for the experiment--that is the light beam emerging from the slit.

The experiment then consists of setting the motor speed so the deflection of the image is some multiple of 1/2 mm and then determining the motor speed from the distance between spikes on the scope trace or from a stationary Lissajous pattern set up by an auxiliary oscillator driving the horizontal scope deflection.

I suggest leaving the optical bench rod and supports and attachments as they are; the height is right to fit under Kerr cell used later, the length is needed later. Generally when people change things around, the set up is a botched up mess. Results can be obtained with less than optimum arrangement and maybe the student does not learn as much about setting things up but he doesn't learn anything doing it wrong and not knowing it IS poor either.

Since the deflections of the image are not large, precision is only achieved by making several runs. Deflection can be plotted vs. motor RPM and “C” is evaluated from the expression for the slope. Realize that more weight should be given the larger deflection points than those of small deflection, given that one can't set the image closer than .1 mm whatever the deflection.

The beam splitter has two clips--one for thin microscope slides and the other for the thicker half reflecting mirror. If one does not believe the calibration dial of the H-P oscillator that can be calibrated against the line frequency or from a standard 60 cycle source in the rolling instrument cabinet. Do not leave the motor screaming away if not making measurements. So far nothing has flown apart but I always wonder.

Rotating Mirror – Electrical

The experiment is essentially the same as the above except we use a photomultiplier detector to help us decide when we have a certain image deflection. The optical arrangement is identical to the above so don't disturb it. Remove the scale and eye lens. At the position of the scale, however, we are going to put a slit of variable opening on which the source slit (or the minimum between its doubled image is imaged With the micrometer drive on the source slit, we are going to position it so that a minimum (or maximum if the half silvered beam splitter is used) signal through the slit at the image is achieved.

We have to get light that comes through the exit slit of the apparatus into a photomultiplier. There is a telescope photomultiplier combination. This consists of an end-on photo- multiplier located behind a small aperture at the focus of a two inch (roughly) lens. We need this in the last part of the experiment. It is focused roughly on infinity. To use it with the exit slit in the present arrangement we collimate the light passing through the slit and then look at that with the telescope- multiplier combination. There is another lens identical to the telescope lens which fits into an adapter tube having a slot in one side through which the lens handle will fit when the latter is inside the adapter. The extension handle can be unscrewed from the lens to avoid a long thing sticking out of the adapter. Thus the lens is butted between the telescope and the collimator sleeve, the other, small, end of which takes the slit. In this way the slit is imaged on the photomultiplier aperture and a large fraction of extraneous room light is kept out. Photomultipliers are easily damaged and so overhead room lights should be kept off, and no high voltage applied to the tube with the "non-rotating" image of the source slit falling on the exit slit. It may well be too much for it on a steady basis. The voltage should be such that when it s rotating (that is when the mirror is rotating) the spikes observed present a healthy signal, say, something less than a volt or so. When the mirror is rotating it will be observed that the photomultiplier signal may be maximized or minimized, (depending on whether the signalimage or double image mode is used) moved with the micrometer. The object here as the source slit is moved with the micrometer. The object here is to maintain that extreme by shifting the position of the s it as the mirror rotation speed is changed. The shift in the slit position is read off on the micrometer dial. The motor speed is determined as before except that now the synchronous signal is the light through the exit slit it. The sweep may either be the internal linear sweep or the sine signal from the H-P oscillator, whose frequency is adjusted to obtain a stationary pattern as before.

It will be observed there is considerable latitude in slit position over the light minimum (or maximum) so that one is not doing much well than visually. The accuracy in determining the correct setting can be increased by setting the entrance slit so as to give a scope deflection of half the maximum height on each side of the extremum, being careful to move the slit

n one direction so as to avoid backlash. These settings are reasonably sharp and so the mean in the two micrometer readings will give a reasonably close value for the position of the maximum (or minimum).

No recipe is given for the slit widths--these w adjusted to optimize signal, sharpness of tuning, etc. be t must be noted that it is not enough to simply get the entrance slit image on the exit slit--the collimator-telescope must be aimed properly to let light fall on the collimator lens. This can be done in first approximation by properly aiming the whole unit. In front of the photomultiplier aperture there is a beam splitter in the telescope which deflects some of the image light into a small eyepiece having a crude reticle in its focal plane. This has a circle inscribed on it such that what appears centered in the circle falls on the aperture for the PM. Thus, when a bright line image falls on the exit slit, a portion of the exit slit will appear in the telescope eyepiece with a bright background appearing behind it. As the entrance slit is moved the brightness in the eyepiece varies accordingly. When this obtains one can go ahead, rotate the mirror and bring up the photomultiplier voltage until a signal is observed on the scope and then proceed with the measurements. As before, precision is achieved by making a number of runs. In this case, the motor speed will not be quantized to match successive 1/2 mm deflections of the image.

The telescope-collimator for this is mounted on the wood tripod at the front of the experimental table in the wood saddle arrangement constructed for the purpose.

A variation of this would be to use a Moire fringe technique, using a grid of equally spaced verticle opaque lines of width equal to the spacing for the entrance aperture and a like grid for the exit aperture and tuning the position for a minimum. This has been tried but the fringe contrast is not very good. The half silvered mirror should be used for the beam splitter in this case. Another variation, not tried, would be in the use of an opaque stripe rather than a slit at the entrance aperture which is imaged on the exit slit.

A weak spurious signal may be observed here but it is perfectly normal. Each time the normal to the rotating mirror surface coincides with the beam line, a diverging beam comes back onto the beam splitter and is reflected into the detector. Not having been collected and focused by a lens or mirror, however, it is not imaged at the exit plane and so is not very strong and may not be noticed.

Kerr Cell Technique

For this part of the experiment the 811 spherical concave return mirror is moved to the very far end of the hall and set on the long bench in the alcove there against the north wall of the alcove. The optical bench rod and source are turned end for end on the experimental table and moved to the left end as far as it will go. The box containing the Kerr cell and pulse forming transmission line are set astradle the optical bench and the condenser lens moved out from its previous position relative to the arc lamp such that it forms an image of the arc in the center of the Kerr cell with approximately equal object and image distance configuration. This is readily observed by taking the 1id off the cell box (voltages all OFF) and observing the focus and centering in the nitrobenzene between the condenser plates. Be careful in moving the box about and into position--keep it level to avoid spilling liquid out of the cell. The handles on the polarizing prisms are set approximately parallel and perpendicular to the passed plane of polarization.

These will be set crossed but with the passed plane at about 45° to the applied electric field in the cell Set the two polarizers parallel first. Take the 211 lens out of the previous telescope-collimator set up, screw on the extension handle and mount it on the lens bench (rod). Put on the lens ring the beam splitter of multiple glass plates which can be dusted off without worry of scratching it up. Project the image of the arc in the Kerr cell with this lens down toward the return mirror. If the image is roughly 24 in front of that mirror the beam will come back approximately parallel such that the telescope-multiplier unit will focus it onto the aperture before the multiplier cathode. This is not crucial. With a card upright in front of the telescope the projection lens can be moved to get the most concentrated beam coming into the telescope. For this set up it is convenient to have the telescope close down to the table surface sitting in the adjustable saddle arrangement of brass. To adjust the far mirror in angle, place the cube corner reflector in front of the telescope and go to the mirror and adjust its tilt until, with one's eye right over the edge of the large mirror, the cube corner reflector flashes up. One is pretty sure when he goes back to the experimental table that he will find the beam fairly well centered on the telescope objective. By properly tilting the telescope and aiming it laterally he can bring the bright spot into the center of the circle on the reticle in the eyepiece. Before this is done carefully it is wise to have the other beam splitter mounted over the telescope objective such that the beam reflected off the beam splitter over the projection lens is directed onto this second beam splitter and into the telescope objective. Adjustment in both rotation and angle of tilt of these splitters is required to bring the short path image onto the reticle circle. One can tell when he is getting close by the glare from outside the field of view. The aim is to get both bright spots centered in the reticle circle. By blocking off first one path and then the other one can separate out the two images When this adjustment is achieved the second polarizer can be crossed to the first one, the Kerr cell 1 box closed up and connected to the high voltage supply and the experiment started To get the polarizers crossed one simply observes the images and tunes the second polarizer for minimum intensity. The location of the beam in the cell and the exit aperture from the box are somewhat critical to avoid an internal reflection from something which makes the minimum not as deep as it should be and raises the noise level in the PM during operation.

With adjustments made, the filament is turned on in the high voltage supply and then the plate voltage. The latter is then raised with the Variac control until the spark gap starts breaking down. The closer the gap, the lower this voltage and the higher the repetition frequency. The supply voltage should not go over about 9 kV and the average current not off-scale in general. The cell is now putting out 20 ns second pulses of light which go into the photomultiplier by a short path and a long path. The voltage on the multiplier can now be raised. Signals should be observed before 1 kV is attained on the tube. Get the Tektronix to trigger on the first pulse. When it does, two pulses will appear on the trace. The sweep speed will be on the fastest setting (not with the x5 magnifier until later if then) The two pulses will likely not be of the same amplitude. To bring them to the same height, the adjustable square diaphragm is put in the stronger beam and closed until it is the same height as the smaller beam. One now measures, assuming the oscilloscope sweep calibration is correct, the distance between the two pulses to determine the time difference in their arrival at the PM. Measuring the difference in distances of the two paths lets us get “c”. You may now want to use the x5 magnifier. This is not a very precise determination but is a striking and clear demonstration of the finite velocity of the signal down the hall and back. Of course so are the previous methods but this is so direct as to be impressive.

Run the PM at a level to give reasonable signals, say, on the next to most sensitive amplifier scale of the Tektronix oscilloscope. Be careful to not have any voltage applied to the PM when the polarizers are not crossed.

the tube. It will surely cream.
The principle purpose of the Kerr cell method, however, is to determine the zeros in the frequency analysis of the Fourier spectrum of the two pulses. These will be related to the time difference (or interval between them in the same way that the zeros in a two slit diffraction pattern are related to the separation between the two slits producing the pattern. To make the Fourier analysis one takes the output of the photomultiplier and puts it into the antenna terminal (coaxial cable connection) of a short wave radio receiver. One measures the output as a function of the receiver tuned frequency. Here we are only interested in the zeros or nulls in the noise output of the receiver. The output is surely noise--the buzzing of the spark gap comes out of the speaker. At a number of discreet equally spaced frequencies, the noise output drops to a reasonably sharp minimum. The minimum is not as sharp as one would perhaps like and so to determine the minimum more closely, an old low impedance AC voltmeter is plugged into the speaker plug and the voltage out- put read as a function of the receiver dial reading. From the shape of the resultant variation the minimum can be located graphically more closely than by ear. The receiver can be calibrated by using the BC-221 meter to better than one part in 104-105. It reads reasonably well if the band spread dial is set to the right hand end of the band spread scale. It should be possible to observe five or six nulls, some better than others. At the null, interruption of one beam (either beam) will increase the noise level. the noise. Off the num., interruption of either beam decreases. It may well be that for other than the fundamental possibly even for that) that adjustment of the square attenuating aperture in the one strong) beam will improve the minimum. But it shouldn't be a great improvement.

But there is no recipe for maximizing by receiver adjustment the signal to null ratio at the minimum. Adjustment of the effective Q(band width) control, noise limiter, etc. can enhance the null
Fiddle is the word here. Suffice it to say that the effect is large and pronounced and that quite respectable value of “c” result from the method.

To understand how the receiver produces these nulls, aside from some nice mathematical relations, consider the shock excitation of a resonant circuit such as stands at the input of the receiver. Then see what the net result is if another shock excitation is introduced of the same magnitude at the appropriate phase in the decaying oscillation produced by the first shock. It is clear then what is going on.