THE SPEED OF LIGHT

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Physics 480a
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INTRODUCTION:

The method used in this experiment to determine the speed of light through the air in our lab was first developed around 1850 by Foucault, and then modified by Michelson in 1878. To determine the speed of light, c, one simply times a pulse of light as it travels over a distance, x; $c = x/t$.

APPARATUS:

A laser beam of red light passes through a beam splitter onto a rotating mirror. Then through a lens, to help focus the beam, to a plane reflecting mirror set up perpendicular to the path of the beam. The beam should be reflected back along the path it came, and be deflected by the beam splitter onto a glass scale where a change in position of the beam can be measured through a small telescope mounted on a smaller scale.

see figure 1 next page

THEORY:

The distance, x, is defined as twice the distance between the rotating mirror and the plane reflecting mirror; 2D. The time, t, is determined by the frequency, f, of the rotating mirror and the distance, s, associated with the angle, ϕ. As the rotating mirror moves through angle ϕ, the pulse of light returning from the plane reflecting mirror is reflected an angle 2ϕ, by the rotating mirror.* With the mirror rotating at an angular velocity $w = 2\pi f = \phi/t$, through angle ϕ, in time t, which produces the defected distance, $s = 2\phi r$, where $r = r_1 + r_2$. Bringing all the above quanties together, one obtains the following derivation of the speed of light.

* Snell's law of reflection

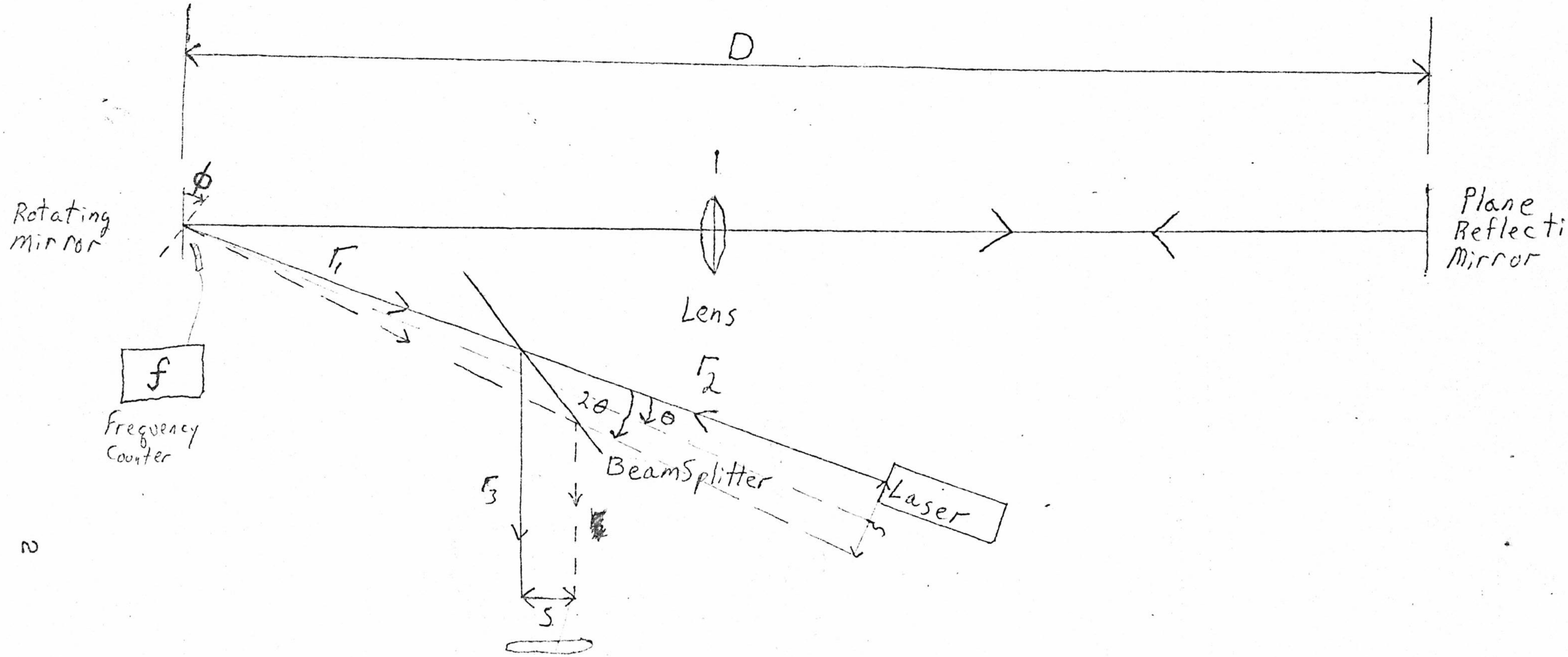
D
Rotating mirror
Plane Reflectin
Mirror
Lens
r_1
r_2
r_3
2θ
θ
Beam Splitter
Laser
f
Frequency Counter
S
ϕ

figure 1

DERIVATION:

$$x=2D$$

$$w=\phi/t$$

$$t=\phi/w=\phi/2\pi f$$

$$s=2\phi r$$

$$\phi=s/2r$$

$$t=s/4\pi rf$$

$$c=x/t=2Df4\pi r/s.$$

However, since the mirror is silvered on both sides ,

$f_{com}=\frac{1}{2}f_{counter}$ so that:

$$c=4\pi rDf/s.$$

PROCEDURE:

Setting up the apparatus can be done easily by setting things up as shown in figure 1, and then find out where the lens focuses the beam the best, and line up the beams between the two mirrors so that they coincide with each other. Once this is done there should appear a small red dot on the glass scale. (Note that the glass scale is not used in making measurements.) The telescope is placed so that the red dot is in the center of the field of view, and the reading off the telescope mounting's scale is recorded as the zero point; $s=0$. The mirror is then started rotating at a frequency, f, and as the frequency is changed, s is changed. A whole range of frequencies are gone through, up to certian limitations of the equip ment. Data is recorded up and back down the whole r ange, and the frequencies are plotted against the distance s. The measurements of D and r must also be made; a tape measure may be used for that purpose.

RESULTS:

The results of this experiment can be seen from the error analysis. The speed of light, c, was found to be approximatly, 3×10^{10} cm/sec. The largest error involved came from taking readings off the telescope mounting's scale. Although these readings were taking using a magnifying glass, they were still a bit shaky. So even though the scale went down to .0001 cm, it could not be read that accurately because of dents in the scale, and missing grid lines. There also seemed to be less error associated with higher frequencies, by a factor of about 2. This was simply because the realitive errors in s and f get smaller as their respective quantities get larger. For example:

from:

#4 $c \pm \Delta c = (3.00 \pm .15) \times 10^{10}$ cm/sec

#11 $c \pm \Delta c = (3.05 \pm .08) \times 10^{10}$ cm/sec

The accepted value for 'c', in air, at the earth's surface is:

2.997×10^{10} cm/sec.

$3.00 - .15 = 2.85$ cm/sec

$3.05 - .08 = 2.97$ cm/sec

Thus, the experiment was successful within the given errors.

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April 27, 1981

DATA: S' is the distance reading on the telescope's scale. This reading was the hardest reading to obtain because of the size of the scale; which was so small that a small magnifying glass was used in order to obtain readings that were accurate to .005 cm.

reading #	S'(cm.)	S(cm.)	f(1/sec.)
1	10.773	0	0
2	10.677	.056	200
3	10.645	.088	315
4	10.626	.107	406
5	10.605	.128	499
6	10.587	.148	558
7	10.568	.165	623
8	10.555	.178	681
9	10.536	.197	760
10	10.515	.218	834
11	10.505	.228	879
12	10.522	.211	829
13	10.530	.203	792
14	10.540	.193	743
15	10.557	.176	702
16	10.573	.160	614
17	10.595	.138	558
18	10.606	.129	486
19	10.643	.092	357
20	10.669	.066	231
21	10.733	0	0

SAMPLE CALCULATIONS:

The distance, D, was measured to be 1400±15 cm. The distance r, was measured to be 450±5cm.

Sample calculations and error analysis are done for reading numbers 4 and 11.

$$C = 4\pi r D f/s = 4\pi(1400)(450)\frac{f}{s} = \underbrace{79156813.48}_{"k"}\frac{f}{s}$$

$$\#4 \quad C = k\cdot\frac{406}{.107} = 3.003949 \times 10^{10} \text{ cm/sec}$$

$$\#11 \quad C = k\cdot\frac{879}{.228} = 3.052 \times 10^{10} \text{ cm/sec.}$$

ERROR ANALYSIS:

The errors involved in this experiment are:

$f \pm \Delta f;\ \Delta f = 2\ sec^{-1}$ $\quad S \pm \Delta S;\ \Delta S = .005\ cm$

$D \pm \Delta D;\ \Delta D = 15\ cm$ $\quad r \pm \Delta r;\ \Delta r = 5\ cm$

$$\frac{\Delta c}{c} = \left[\left(\frac{\Delta f}{f}\right)^2 + \left(\frac{\Delta S}{S}\right)^2 + \left(\frac{\Delta D}{D}\right)^2 + \left(\frac{\Delta r}{r}\right)^2\right]^{1/2}$$

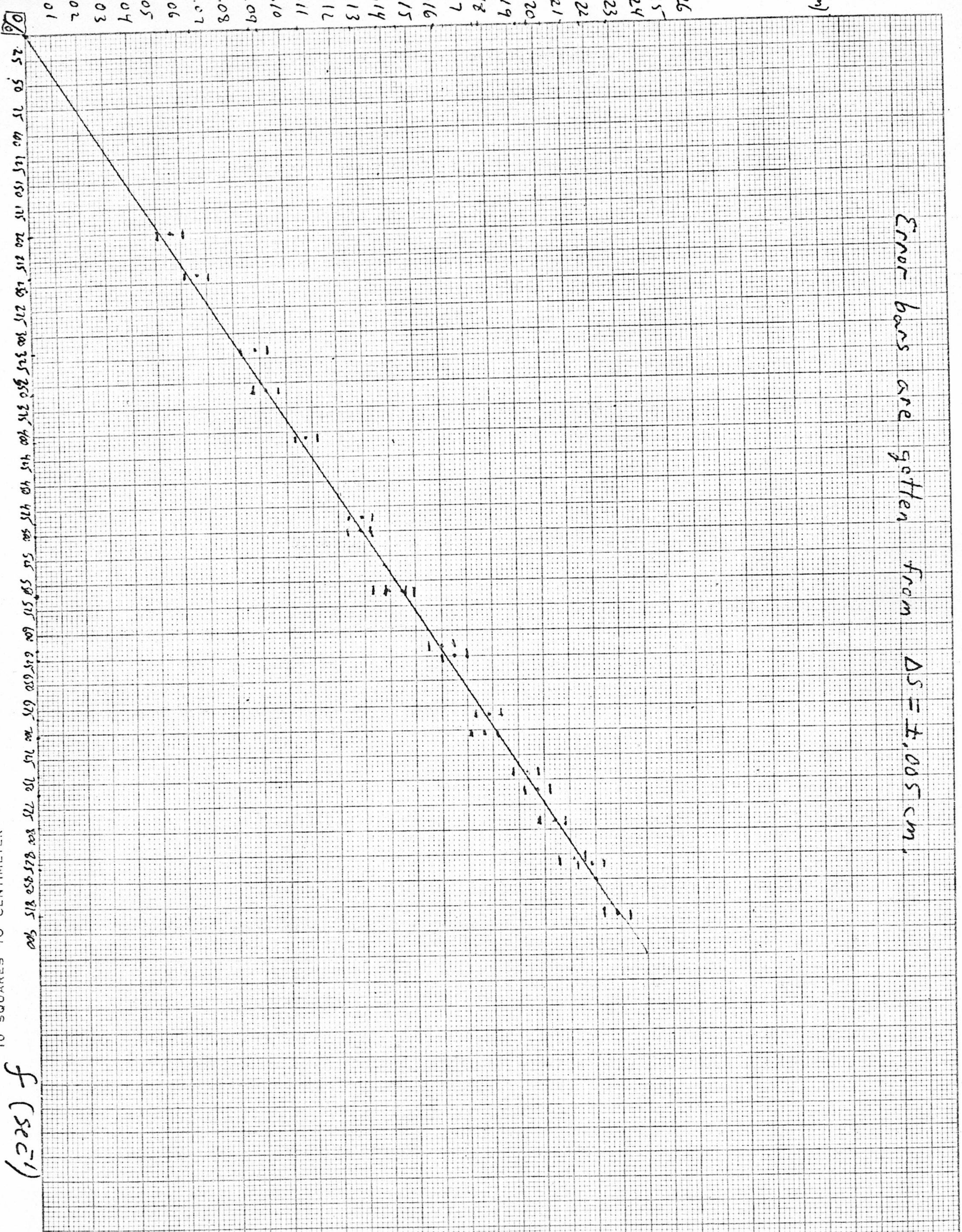
$$\#4 \quad \frac{\Delta c}{c} = \left[\left(\frac{2}{406}\right)^2 + \left(\frac{.005}{.107}\right)^2 + \left(\frac{15}{1400}\right)^2 + \left(\frac{5}{450}\right)^2\right]^{1/2}$$

$$= \left[.00002 + \underline{.00218} + .000114 + .0001234\right]^{1/2}$$

$$= .049 \Rightarrow C = (3.00 \pm .15) \times 10^{10} \text{ cm/sec}$$

$$\#11 \quad \frac{\Delta c}{c} = \left[\left(\frac{2}{879}\right)^2 + \left(\frac{.005}{.228}\right)^2 + (.000114 + .0001234)\right]^{1/2}$$

$$= .02689 \Rightarrow C = (3.05 \pm .08) \times 10^{10} \text{ cm/sec.}$$



Error bars are gotten from ΔS = ±.005 cm.
f (sec⁻¹)
.01 .02 .03 .04 .05 .06 .07 .08 .09 .10 .11 .12 .13 .14 .15 .16 .17 .18 .19 .20 .21 .22 .23 .24 .25 .26
cm)