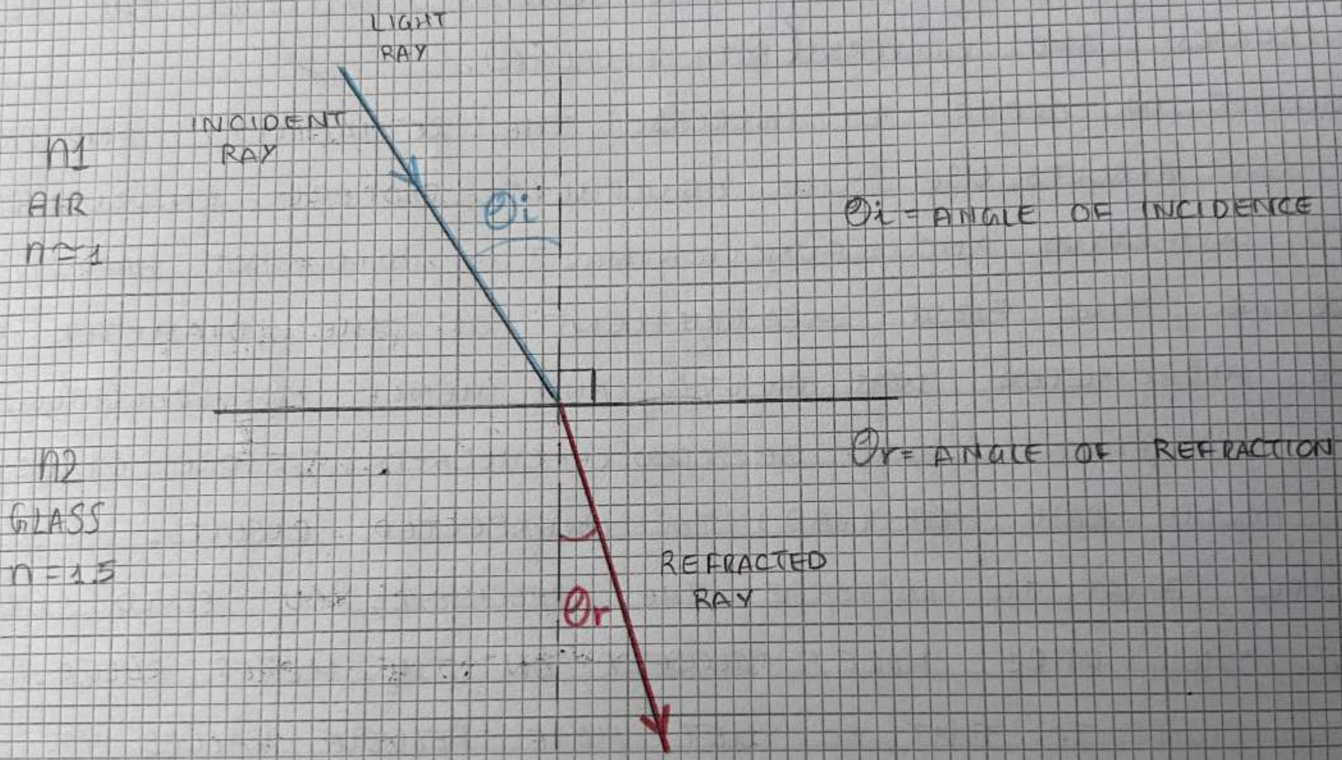


REPRESENTATION OF A BEAM OF LIGHT INCIDENT ON A BOUNDARY WITH GLASS

very good

PHYSICS LAB 3 – SNELL'S LAW 08/02/2023

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AIM: THE AIM OF THIS EXPERIMENT IS TO DETERMINE THE REFRACTIVE INDEX OF A GLASS BLOCK USING SNELL'S LAW. ~~AND A GRAPH WITH THE LINE OF BEST FIT.~~

BACKGROUND: THE REFRACTIVE INDEX OF A MATERIAL IS THE RATIO BETWEEN THE SPEED OF LIGHT IN THE MATERIAL ($v_m$) AND THE SPEED OF LIGHT IN A VACUUM ($c$):

$c \approx 3 \times 10^8 \ ms^{-1}$

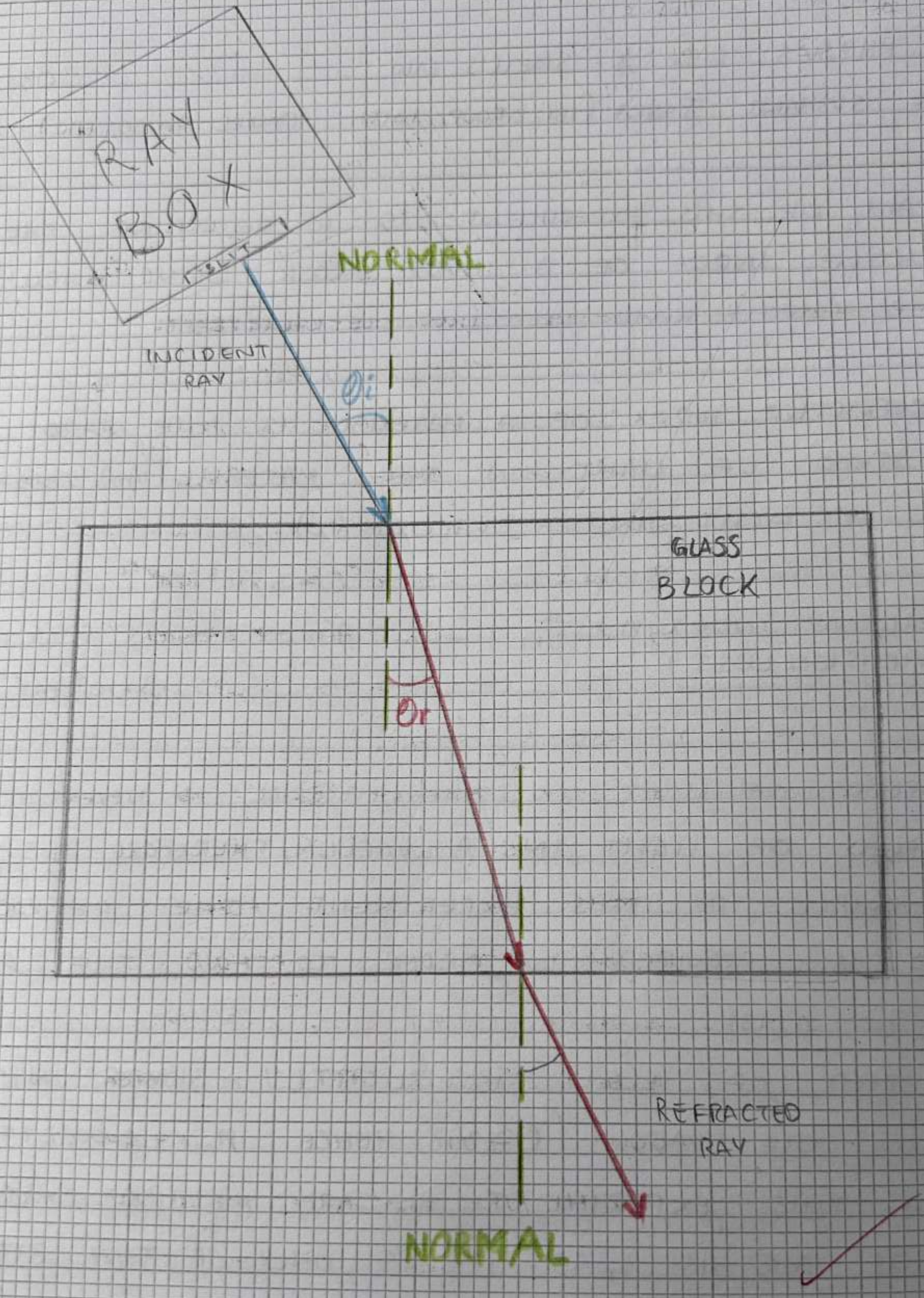
REFRACTIVE INDEX, $n = \frac{c}{v_m}$ (DIMENSIONLESS)

$v_m \rightarrow$ ALWAYS LESS THAN $3 \times 10^8 \ ms^{-1}$

- THE SPEED OF LIGHT IN THE MATERIAL IS NEVER BIGGER THAN THE SPEED OF LIGHT IN A VACUUM, THEREFORE $n = \frac{c}{v_m} > 1$. FOR EXAMPLE IN THIS EXPERIMENT THE REFRACTIVE INDEX OF AIR IS REQUIRED IN ORDER TO FIND THE REFRACTIVE INDEX OF GLASS.
- THE SPEED OF LIGHT IS SLIGHTLY SLOWER IN THE AIR THAN IN THE VACUUM ($c \simeq v_m$) HENCE $n_{AIR} = 1.000277$.
- THROUGH THIS EXPERIMENT WE ARE ASSUMING THAT REFRACTIVE INDEX OF AIR IS 1, AS IT IS ONLY A TINY BIT LARGER THAN 1.
- THE REFRACTIVE INDEX OF GLASS, INSTEAD, IS ABOUT 1.5; THAT MEANS THE LIGHT TRAVELS SIGNIFICANTLY SLOWER IN GLASS THAN IT DOES IN A VACUUM ($v_m \simeq 2 \times 10^8 ms^{-1}$).
- THEREFORE, TO ACHIEVE THE EXPERIMENT'S AIM, IT IS EXPECTED A RESULT AROUND 1.5.
- IN ORDER TO FIND THAT, SNELL'S LAW IS NEEDED;

– SNELL'S LAW RELATES THE ANGLE OF INCIDENCE AND REFRACTION TO THE MATERIAL PROPERTIES AND THE SPEED OF WAVE.

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$



RAY
BOX
SLIT
NORMAL
INCIDENT
RAY
θi
GLASS
BLOCK
θr
REFRACTED
RAY
NORMAL

THEREFORE
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
(SNELL'S LAW)

$n_1$ = REFRACTIVE INDEX OF THE INCIDENT MAT.
$n_2$ = REFRACTIVE INDEX OF THE REFRACTED MAT.
$\theta_1$ = ANGLE OF INCIDENCE (THE ANGLE TO THE NORMAL)
$\theta_2$ = ANGLE OF REFRACTION (IT IS DIFFERENT TO $\theta_i$)

- AS THE AIM IS TO FIND THE REFRACTIVE INDEX OF THE REFRACTED MATERIAL, IT IS POSSIBLE TO REARRANGE THE EQUATION:

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2} \longrightarrow$$ $n_1$ IS KNOWN ($n_1 = 1$), $\theta_1$ AND $\theta_2$ WILL BE MEASURED DIRECTLY.

- WRITING DOWN THE SNELL'S LAW EQUATION, IT IS NOTICEABLE HOW THIS IS SIMILAR TO THE EQUATION OF A STRAIGHT LINE:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \xrightarrow{n_1 = 1 \text{ (ASSUMPTION)}} \sin\theta_1 = n_2 \cdot \sin\theta_2$$

$$y = mx + c \longrightarrow y = m \cdot x$$

GRADIENT, $m = \frac{\Delta y}{\Delta x}$

$y = \sin\theta_1$; $m = n_2$; $x = \sin\theta_2$

- A GRAPH WITH $\sin\theta_1$ ON THE Y-AXIS AND $\sin\theta_2$ ON THE X-AXIS IS DRAWN IN ORDER TO FIND THE GRADIENT (m), AND IT IS EXPECTED THAT THE GRAPH SHOWS A STRAIGHT LINE (IN THE MIDDLE OF THE POINTS). AS THE Y-INTERCEPT IS NOT PRESENT IN THE EQUATION (THEREFORE $c = 0$), IT IS EXPECTED THAT THE LINE OF BEST FIT PASSES THROUGH THE ORIGIN.
- DURING THE EXPERIMENT, THERE COULD BE A PHENOMENON CALLED TOTAL INTERNAL REFLECTION (TIR).

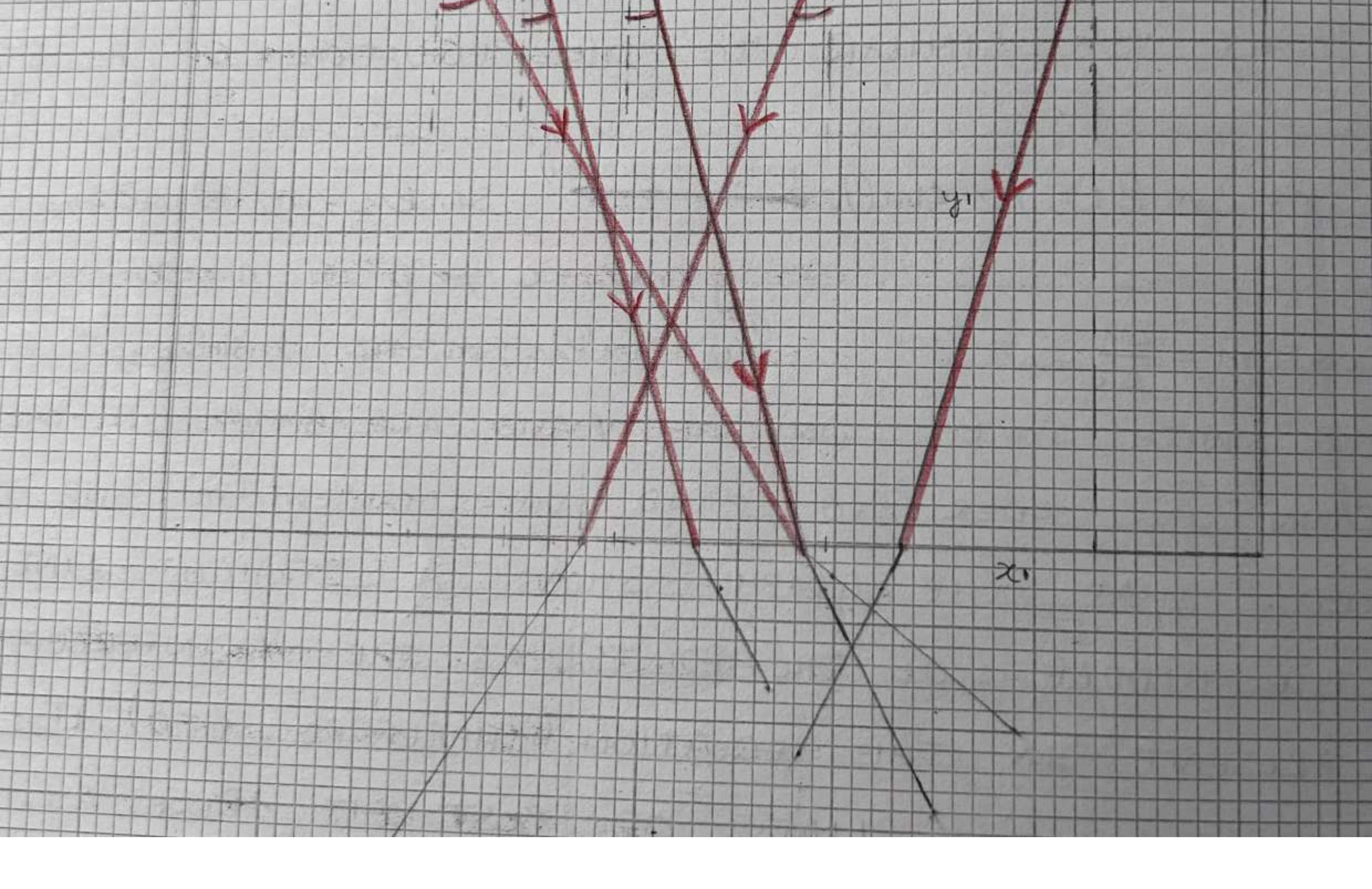
AS THE ANGLE OF INCIDENCE IS INCREASED, THE ANGLE OF REFRACTION INCREASES AS WELL, UNTIL IT HITS 90 DEGREES. THE ANGLE OF ~~THIS~~ INCIDENCE AT THIS POINT IS CALLED THE CRITICAL ANGLE ($\theta_c$). IF THE ANGLE OF INCIDENCE IS GREATER THAN THE CRITICAL ANGLE, NO REFRACTION WILL OCCUR.

Good point

~~HOWEVER, $\theta_c$ ONLY EXISTS IF $n_1 > n_2$, THEREFORE THE EXISTS~~

THE LIGHT WILL JUST BE REFLECTED BACK, LEADING TO THE TIR. HOWEVER, $\theta_c$ ONLY EXISTS IF $n_1 > n_2$, THEREFORE IN THIS EXPERIMENT $\theta_c$ DOES NOT EXIST AND AFTER A CERTAIN ANGLE, THERE WILL BE TIR.

METHOD & EQUIPMENT:


= INCIDENT RAY AND θi
= REFRACTED RAY AND θr
1
2
3
4
5
x
y
y'
x'

EQUIPMENT:

- GLASS BLOCK
- LIGHT SOURCE (RAY BOX)
- SLITS
- RULER
- PROTACTOR
- GRAPH PAPER

METHOD: (REFER TO THE FIGURE AT PAGE 24 & PAGE 26)

- THE GLASS BLOCK WAS PLACED ON A SHEET OF PAPER AND IT WAS DRAWN ROUND IT;
- ONE OF THE SLITS WAS PLACED INTO THE RAY BOX;
- ~~MAKE SURE~~ IT WAS CHECKED THAT THE RAY BOX WAS POSITIONED AT A RELATABLE DISTANCE (A DISTANCE WHERE YOU CAN BEST SEE THE BEAM OF LIGHT THROUGH THE EXPERIMENT);
- A LIGHT RAY WAS SHONE INTO THE BLOCK AND IT WAS MARKED WHERE IT STARTS, ENTERS, LEAVES AND FINISHES;
- THESE 4 POINTS OF EACH DIFFERENT LIGHT RAY WERE THEN CONNECTED USING A RULER TO FORM THE INCIDENT RAY, THE ANGLE OF INCIDENCE, THE REFRACTED RAY, AND THE ANGLE OF REFRACTION;
- TWO LINES TO THE NORMAL WERE DRAWN (AT THE POINT WHERE THE LIGHT RAY ENTERS AND LEAVES THE BLOCK);
- A TABLE WAS DRAWN (WITH HEADINGS $\theta i$ (°C), $\theta r$ (°C), $\sin\theta i$, $\sin\theta r$, n2)

FIRST METHOD TO FIND n2

- IN EACH LIGHT RAY $\theta_1(\theta i)$ AND $\theta_2(\theta r)$ WERE MEASURED ~~AND~~ DIRECTLY WITH THE PROTRACTOR AND RECORDED ON THE TABLE; ~~CONSEQUENTLY~~ ~~n2 WAS CALCULATED WITH THE FORMULA STATED IN THE BACKGROUND;~~
- $\sin\theta i$ AND $\sin\theta r$ WERE THEN CALCULATED;
- ~~n2 WAS CALCULATED~~ AS STATED IN THE BACKGROUND, n2 WAS THEN CALCULATED USING SNELL'S LAW EQUATION REARRANGED; $\left(n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}\right)$ → FIRST METHOD TO CALCULATE n2
- A GRAPH OF $\sin\theta i$-$\sin\theta r$ WAS PLOTTED AND THE RESULTS WERE MARKED;

SECOND METHOD TO DETERMINE n2

- ONCE THE LINE OF BEST FIT WAS DRAWN, IT WAS POSSIBLE TO FIND m, THEREFORE THE REFRACTIVE INDEX OF THE GLASS BLOCK (n2).

THIRD METHOD TO FIND n2

- DURING THE EXPERIMENT, IT WAS NOTICEABLE THAT THE NORMAL LINE AND THE LIGHT RAY FORMED A RIGHT-ANGLE TRIANGLE, THEREFORE IT WAS POSSIBLE TO USE THE THREE MAIN TRIGONOMETRIC RATIOS (SOH CAH TOA);

EXAMPLES: ~~...~~ LIGHT RAY 5

- FIRST MEASURE $x, x_1, y, y_1$;
- ONCE $\sin\theta i \left(\frac{OPP(x)}{HYP(y)}\right)$ AND $\sin\theta r$ WERE CALCULATED, n2 WAS DETERMINED USING THE SNELL'S LAW REARRANGED $\left(n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}\right)$;
- THE THREE METHODS WERE THEN COMPARED TO SEE WHICH ONE WAS ~~MORE~~ GIVING n2 MORE ACCURATE (THIRD METHOD WAS USED ONLY FOR A PART OF THE RESULTS)

| LIGHT RAY | $\theta_i$ (°C) | $\theta_r$ (°C) | sim $\theta_i$ | sim $\theta_r$ | $n_2 \left(\frac{\text{sim } \theta_i}{\text{sim } \theta_r}\right)$ |
|---|---|---|---|---|---|
| 1 | 51.0 | 31.5 | 0.7771 | 0.5225 | 1.49 |
| 2 | 27.0 | 17.5 | 0.4540 | 0.3007 | 1.51 |
| 3 | 26.5 | 17.0 | 0.4461 | 0.2924 | 1.52 |
| 4 | 32.0 | 20.0 | 0.5300 | 0.3420 | 1.55 |
| 5 | 22.0 | 16.0 | 0.3746 | 0.2756 | 1.36 → OUTLIER |
| 6 | 26.0 | 16.0 | 0.4384 | 0.2756 | 1.59 |
| 7 | 33.0 | 21.0 | 0.5446 | 0.3584 | 1.52 |
| 8 | 27.0 | 17.0 | 0.4540 | 0.2924 | 1.55 |
| 9 | 53.0 | 31.0 | 0.7986 | 0.5150 | 1.55 |
| 10 | 25.0 | 16.0 | 0.4226 | 0.2756 | 1.53 |
| 11 | 36.0 | 22.0 | 0.5878 | 0.3746 | 1.57 |

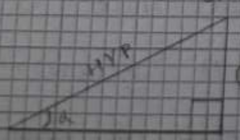
$1^{st}$ METHOD TABLE

$3^{rd}$ METHOD TABLE

| LIGHT RAY | OPP ($x$ | ; $x_1$) | HYP ($y$ | ; $y_1$) | sim $\theta_i \left(\frac{x}{y}\right)$ | sim $\theta_r \left(\frac{x_1}{y_1}\right)$ | $n_2 \left(\frac{\text{sim } \theta_i}{\text{sim } \theta_r}\right)$ | ERROR IN LENGHT ($x, x_1, y, y_1$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 3.15 | 4.10 | 4.05 | 7.70 | 7/9 | 41/77 | 1.46 | ±0.01 |
| 2 | 1.60 | 2.00 | 3.60 | 6.90 | 4/9 | 20/69 | 1.53 | ±0.01 |
| 3 | 1.40 | 1.95 | 3.15 | 6.90 | 4/9 | 13/46 | 1.57 | ±0.01 |
| 4 | 2.95 | 2.60 | 5.65 | 7.10 | 59/113 | 26/71 | 1.43 | ±0.01 |
| 5 | 1.00 | 1.95 | 2.30 | 6.85 | $\frac{10}{23}$ | $\frac{39}{137}$ | 1.53 | ±0.01 |

→ THESE ERRORS ARE THE ERRORS IN EACH MEASUREMENT OF LENGTH (WHEN MEASURING WITH RULER), THEREFORE BEING ADDED THE ERROR WOULD BE BIGGER.

$x, x_1, y, y_1$ ARE LABELLED ON LIGHT RAY 5, SO IT CAN BE EASIER TO UNDERSTAND HOW MEASUREMENTS WERE TAKEN




$$\text{sim } \alpha = \frac{OPP}{HYP}$$

SOHCAHTOA

RESULTS & CALCULATIONS: $1^{st}$ READING OF $\theta i$ (°C) WITH PROTRACTOR: (REFER TO $1^{st}$ METHOD TABLE)

$\theta i = 51°$ $\xrightarrow{\text{THEREFORE}}$ $\sin \theta i \approx 0.7771$

$\theta r = 31.5°$ $\xrightarrow{\text{THEREFORE}}$ $\sin \theta r \approx 0.5225$

$$n2 = \frac{n1 \sin \theta i}{\sin \theta r} \xrightarrow{\text{ASSUMING } n1 = 1} n2 = \frac{\sin \theta i}{\sin \theta r} = \frac{\sin(51)}{\sin(31.5)} = 1.49 \text{ (DIMENSIONLESS)}$$

$1^{st}$ METHOD

- THE REST OF $\sin \theta i$, $\sin \theta r$, n2 WERE FOUND FOLLOWING THE SAME PROCEDURE AND USING THE SAME CALCULATION

$3^{rd}$ METHOD $5^{th}$ LIGHT RAY CALCULATIONS: (REFER TO $3^{rd}$ METHOD TABLE AND PAGE 26)

$x, x_1, y, y_1$ ARE LABELLED ON LIGHT RAY 5, AS IT CAN BE (PAGE 26) EASIER FOR THE READER TO UNDERSTAND THE MEASUREMENTS.

Is 0.01 cm a bit optimistic?

$x = 1 cm \pm 0.01$ ; $y = 2.30 cm \pm 0.01$ $\longrightarrow$ $\sin \theta i = \frac{x}{y} = \frac{1}{2.30} = 10/23$

$x_1 = 1.95 cm \pm 0.01$ ; $y_1 = 6.85 cm \pm 0.01$ $\longrightarrow$ $\sin \theta r = \frac{x_1}{y_1} = \frac{1.95}{6.85} = 39/137$

$$\text{THEREFORE, } n2 = \frac{\sin \theta i}{\sin \theta r} = \frac{10/23}{39/137} = 1.53 \text{ (DIMENSIONLESS)}$$

- THE REST OF $\sin \theta i$, $\sin \theta r$, n2 WERE FOUND USING THE SAME PROCEDURE AND CALCULATION.

➤ THE $3^{rd}$ METHOD WOULD GIVE A HIGHER RESOLUTION BUT THERE MIGHT BE A HIGHER ERROR BECAUSE THE MEASUREMENT ERRORS WILL BE COMPOUNDED (ERRORS OF $x, x_1, y, y_1$).
THEREFORE THE $3^{rd}$ METHOD BEING MORE INNACURATE WAS RULED OUT.
AFTER THIS, THE $1^{st}$ AND $2^{nd}$ METHOD WERE LEFT.

$1^{st}$ METHOD

- IN ORDER TO VERIFY THE ACCURACY OF THE $1^{st}$ METHOD, AN AVERAGE VALUE OF n2 IS CALCULATED:

$$n2_{\text{AVERAGE}} = \frac{n2(1+2+3+4+5+6+7+8+9+10+11)}{11} = \boxed{1.52} \text{ (DIMENSIONLESS)} \approx 1.5$$

↓ EXPECTED RESULT

$$n2_{\text{AVERAGE WITHOUT OUTLIER}} = \frac{n2(1+2+3+4+6+7+8+9+10+11)}{10} = 1.54$$

$2^{nd}$ METHOD: NOW THAT THE LINE OF BEST FIT IS DRAWN, IT IS POSSIBLE TO FIND m:

$$m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{0.7986 - 0}{0.52 - 0} = \boxed{1.53} \text{ (DIMENSIONLESS)} \simeq 1.5 \text{ (EXPECTED RESULT)}$$

AS STATED EARLIER:

$$\underbrace{1 \cdot \sin \theta_i}_{\sin \theta_i} = n_2 \cdot \sin \theta_r \longrightarrow y = m x + \underset{0}{c}$$

$$\boxed{1 \cdot \sin \theta_i = 1.53 \sin \theta_r}$$

$y = \sin \theta_i$

$x = \sin \theta_r$

$m = n_2$

$c = 0$ (PASS THROUGH THE ORIGIN)

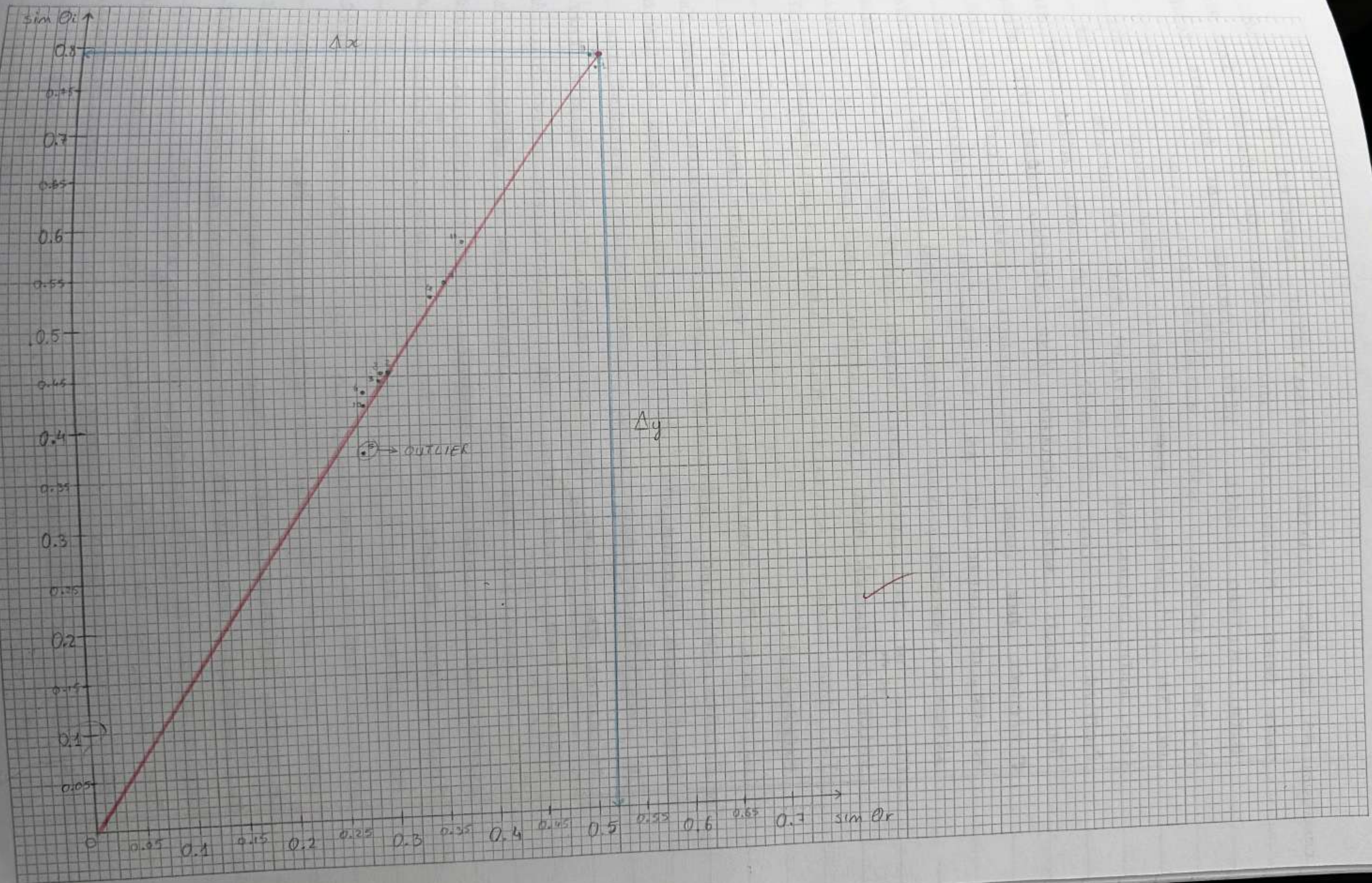
~~CONCLUSION~~ $\% \text{ ERROR} = \frac{|\text{EXPECTED} - \text{CALCULATED}|}{\text{EXPECTED}} \times 100$

| | CALCULATED RESULT | EXPECTED RESULT |
|---|---|---|
| $1^{st}$ METHOD | $n_2 = 1.52$ | $n_2 = 1.5$ |
| $2^{nd}$ METHOD | $n_2 = 1.53$ | $n_2 = 1.5$ |

$\% \text{ ERROR } 1^{st} \text{ METHOD} = \frac{|1.50 - 1.52|}{1.50} \times 100 = 4/3 \simeq 1.3\%$

$\% \text{ ERROR } 2^{nd} \text{ METHOD} = \frac{|1.50 - 1.53|}{1.50} \times 100 = 2\%$

$\% \text{ ERROR } 1^{st} \text{ METHOD WITHOUT OUTLIER} = \frac{|1.50 - 1.54|}{1.50} \times 100 = 8/3 \simeq 2.6\%$


sin θi
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
sin θr
Δx
Δy
OUTLIER

CONCLUSION: AS IT WAS STATED INITIALLY, THE EXPECTED RESULT MUST HAVE BEEN AROUND 1.5 IN ORDER TO ACHIEVE THE AIM. BOTH METHOD GAVE VERY PRECISE AND ACCURATE RESULTS AS THE % ERRORS WERE 1.3% (2.6%) AND 2%. IN THE 1st METHOD ~~THERE WERE~~ 2 AVERAGE VALUES WERE USED (ONE WITH OUTLIER, ONE WITHOUT). IN THE 2nd METHOD WHILE PLOTTING THE LINE OF BEST FIT, IT WAS NOTICE THAT ALL THE POINTS WERE ACCURATE AND PRECISE, EXCEPT THE OUTLIER. THEREFORE THE LINE WAS DRAWN WITHOUT CONSIDERING THE OUTLIER. IF THERE IS AN OUTLIER, THE MEASUREMENT SHOULD BE REPEATED. HOWEVER, BOTH METHODS CAN BE USED TO DETERMINE n2, BUT IN THIS CASE THE GRAPH GAVE US A MORE ACCURATE VALUE OF n2 (2% ERROR). ALSO THE GRAPH CAN HELP US VISUALLY TO SPOT ANY ACCURACY AND VERIFY THE ACCURACY OF THIS EXPERIMENT.

IN ORDER TO INCREASE THE RELIABILITY AND PRECISION OF THE RESULTS, USE THE EQUIPMENT PROPERLY ENSURING THAT THE HANDS AND EQUIPMENTS ARE STILL WHILE TAKING A MEASUREMENT. IN THIS CASE THERE ARE SOME CONSIDERATION REGARDING THE PROTRACTOR, THE RULER AND GLASS BLOCK. IT IS UNLIKELY THAT DURING THE EXPERIMENT THESE EQUIPMENTS WERE STILL AND THE 4 POINTS OF THE LIGHT RAY (WHERE IT STARTS, ENTERS LEAVES AND FINISHES) WERE ~~EXACTLY~~ MARKED PERFECTLY. THEREFORE, THESE TINY ERRORS MUST BE CONSIDERED AND WE SHOULD BE MORE CAREFUL, STILL AND PRECISE.

BESIDES THAT, AS MENTIONED IN THE BACKGROUND, THE REFRACTIVE INDEX OF AIR IS NOT EXACTLY 1, BUT MORE PRECISELY 1.000277. THEREFORE, THROUGH THE EXPERIMENT WE ASSUMED THAT $n_{AIR}$ WAS 1 TO SIMPLIFY THE CALCULATION, THIS TINY DIFFERENCE SHOULD ALSO BE CONSIDERED IN OUR EXPERIMENT.

THE PRECISION OF THE GRAPH IS RELIABLE (THE BEST FIT LINE) AND THE REFRACTIVE INDEX IS ~~MORE~~ NEARER TO THE EXPECTED RESULT, THEREFORE THE 2nd METHOD OF CALCULATION IS BETTER AND THE AIM OF THE EXPERIMENT IS ACHIEVED.

73/75

This is excellent work. My only criticism is that the measurement error estimates are very small and not really justified.