Interferometer

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2 Weight Lab

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Abstract
This experiment was conducted to determine the wavelength of a green laser, the index of refraction of a square plate and the thermal expansion coefficient of Aluminum. This is achieved by investigating the interference of light beams using the Michelson interferometer setup.

To determine the wavelength of the green laser, the path length is varied with a movable mirror. Using the number of fringes that appeared, the wavelength of the green laser, 620 ± 40nm, has a 16.5% difference from the accepted value.

To determine the index of refraction, the path length is varied using the rotation mount with the square plate. Using the number of fringes that appeared, the index of refraction of the square plate is 1.46 ± 0.08.

To determine the thermal expansion coefficient of Aluminum, the path length is varied by heating the Aluminum rod and expansion causes the attached mirror to move. Using the number of fringes that appeared, the thermal expansion coefficient of Aluminum is determined to be $22.5\times10^{-6} \pm 0.2\times10^{-6}$ K^{-1}, which has a 5.46% difference from the accepted value.

1 Introduction
An interferometer is a device that enables the study of interference patterns produced by a light source. This experiment uses the Michelson interferometer, which performs *division of amplitude* – where interference occurs due to the splitting of a single light beam into multiple beams.

The objectives of this experiment are to measure the wavelength of a green laser, the index of refraction of a square plate, and the thermal expansion coefficient of Aluminum.

To determine the wavelength of the green laser, the governing equation is

$$N\lambda = 2\Delta x \tag{1}$$

where N is the number of fringes that appear when the movable mirror is moved a distance of Δx. A fringe disappears when the mirror is moved by half a wavelength distance. This wavelength value is used to calculate the index of refraction and the thermal expansion coefficient of aluminium.

To determine the index of refraction of a square plate, the governing equation is

$$N \simeq \frac{t}{\lambda}\theta^2\left(1 - \frac{1}{n}\right) \tag{2}$$

where t is the thickness of the square plate, λ is the green laser wavelength from (1), n is the index of refraction and N is the number of fringes that appear when the rotating mount is rotated by small angles θ.

To determine the thermal coefficient of an aluminium rod, the governing equation is

$$N \simeq \frac{2L_0}{\lambda}\alpha\Delta T \tag{3}$$

where L_0 is the length of the rod at the base temperature before turning on the power supply, λ is the green laser wavelength from (1), α is the thermal expansion coefficient, ΔT is the temperature difference in the rod from the base temperature and N is the number of fringes that appear. Fringes appear due to the power supply heating the aluminium rod, causing it to expand and, hence, decrease the path length.

2 Materials and Methods

2.1 Materials

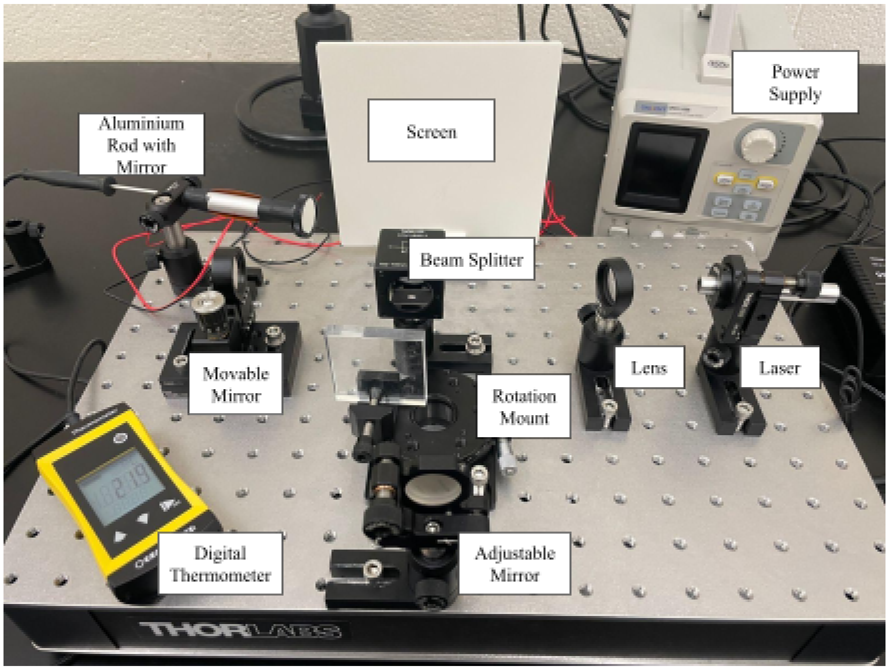

Figure 1. The experimental set-up for the Michelson interferometer.

The experimental set-up consists of the following components:

a. The laser, which produces the beam of light being studied.
b. The lens, through which the beam from the laser passes.
c. The beam splitter, which splits the beam from the laser into two.
d. The movable mirror, with an uncertainty of ±0.5μm, where one division of the moving screw is one micrometer of movement of the mirror.
e. The aiming mirror.
f. The screen, onto which the interference pattern is cast.
g. Additional apparatus for the index of refraction of the square plate:
    i. The plastic square plate
    ii. The rotation mount, with an uncertainty of ±2.5', onto which the square plate is set and rotated
    iii. Vernier calipers, with an uncertainty of ±0.01mm.
h. Additional apparatus for the thermal expansion of aluminum
    i. The digital thermometer
    ii. The aluminum rod
    iii. The power supply for the heater

2.2 Methods

In the Michelson interferometer, light is directed into a lens and consequently through a beam splitter, which splits the light into 2 beams. The first beam goes through a movable mirror while the second goes through an aiming mirror. Both beams enter the beam splitter again, and some light is directed towards a lens, while the rest exits the setup. If the path lengths of both beams are similar, and the beams are aligned, then interference occurs, which is visualised by a concentric circular pattern on the screen.

The positioning and alignment of the interference pattern can be adjusted by either the aiming mirror or the movable mirror. The aiming mirror provides fine adjustment that can move the pattern horizontally or vertically, using two knobs. The movable mirror features a screw that alters the fringes of the interference pattern. By rotating this screw either backwards or forwards, the fringes can either appear (move inwards) or disappear (move outwards).

Wavelength of the Green Laser (λ)

To determine the wavelength of the green laser, the apparatus is set up as described above, and the fringes are made to appear as directed. The number of fringes that appear as the knob of the movable mirror is rotated a distance Δx, is counted. This data is fit to equation (1) to determine the wavelength.

Index of Refraction (n)

To determine the index of refraction of the square plate, the thickness, t, of the square is measured with a Vernier caliper. The square is placed on the rotation mount and rotated such that the beam is perpendicular to it, at an angle noted as the reference angle, against which all other angles are measured. The mount is rotated by various small angles, θ, and the number of fringes, N, that appear are counted. This data, along with the measured green laser wavelength, is fit to equation (2), to determine the index of refraction.

Thermal expansion of Aluminium (α)

To determine the thermal expansion coefficient of aluminium, the movable mirror is replaced with the aluminum rod, and the digital thermometer is set up to record the temperature of the rod. The power source is turned on, and as its voltage is increased in small steps, it heats up the aluminium rod, causing it to expand from an initial length of L_0, to a final length, L. When it expands, the mirror attached at the tip moves forward, changing the path length. The number of fringes, N, that appear as a result are counted. The initial temperature of the aluminium is taken as the zero point, and subsequent change in temperature, ΔT, is measured. This data, along with the measured green laser wavelength, is fit to equation (3) to determine the thermal expansion coefficient.

3 Data and Analysis

Wavelength of the Green Laser

The distance (Δx) moved by the screw of the movable mirror for a set number of fringes (N) is measured and listed in figure 2. The data is fit to the equation

$$N\lambda = 2\Delta x \quad (1)$$

where N is the independent variable and Δx is the dependent variable (Appendix 1.1). N is taken as the independent variable as its uncertainty (±1) is assigned arbitrarily based on our confidence in our ability to reproduce the fringe count for the same Δx.

The gradient of the resulting linear function is $\lambda/2$, determined to be 310 ± 20nm. Hence, the wavelength of the green laser, λ, is found to be 620 ± 40nm (Appendix 2.1).

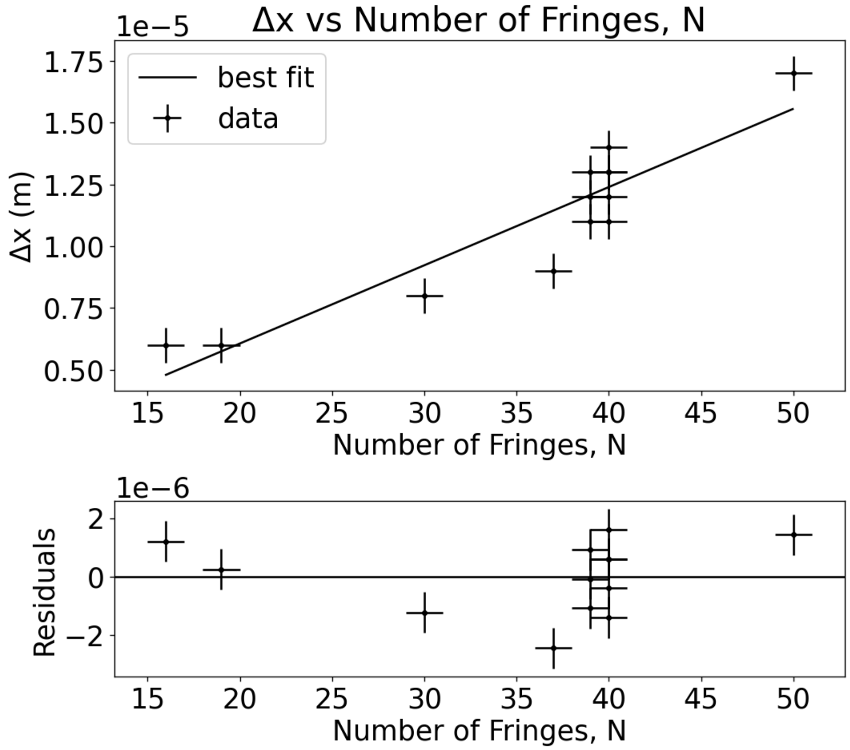

Figure 2. Graph of the number of fringes (N) against distance moved by the movable mirror screw (Δx). The coefficients of the quadratic best fit line (y=mx+b) are m=310±10nm, and b=-270±80nm. The wavelength of the green laser is 620 ± 40nm. From the Residual plot, most data points are within 2 error bars. Hence, this is a good fit.

The manufacturer's description lists the wavelength of this laser as 532nm ± 1nm [1]. The Chi squared value = 1.826. The critical value for 99% confidence at 12 degrees of freedom is 3.571. Since $\chi^2_{calc} < \chi^2_{crit}$, this fitted model is statistically acceptable, and there is no significant difference between the observed and fitted-expected data.

The causes of this discrepancy may be due to an inaccuracy in the alignment of interfering beams or measurement errors when counting fringes. Additionally, the green laser has a distribution of wavelengths it operates in, and it is possible that the diffraction noticed was not for the primary wavelength, but rather at one of the ends of the distribution.

To avoid cascading error in further sections due to error in wavelength measurement in this section, the manufacturer's specification for the green laser's wavelength (532nm ± 1nm) [1] is used for further calculations.

Index of Refraction of the Square Plate

The thickness, *t*, of the square plate was measured to be 7.70 ± 0.01mm. The angle swept by the rotation mount (θ) as a set number of fringes (N) appeared was measured and listed in figure 3. These measurements are fit to the equation

$$N \simeq \frac{t}{\lambda}\theta^2(1 - \frac{1}{n}) \quad (2)$$

and plotted with N as the dependent variable, and θ as the independent variable (Appendix 1.2). The uncertainty for N (±1) is assigned arbitrarily based on our confidence in our ability to reproduce the fringe count for the same θ. The wavelength used in this equation was taken to be 532nm ± 1nm as per the manufacturer's specifications. The resulting graph has a gradient of $(t/\lambda)(1-1/n)$, which gives an n value of 1.46 ± 0.08 (Appendix 2.2).

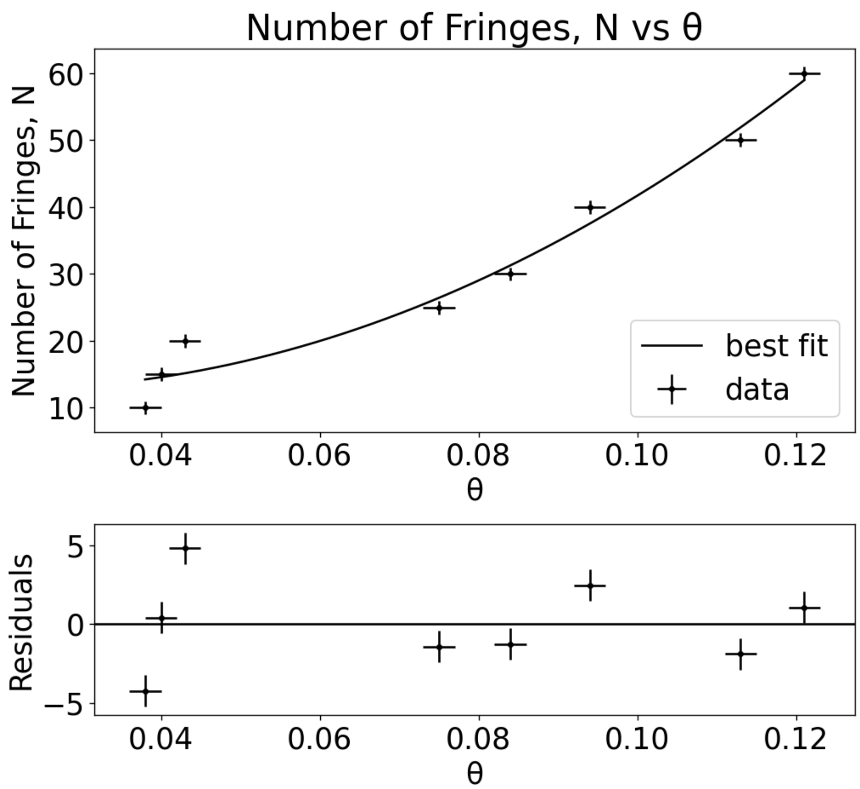

Figure 3. Graph of the number of fringes (N) against angle swept by the rotating mount (θ). The coefficients of the quadratic best fit line ($y=ax^2+bx+c$) are $a=4500\pm500$ rad^{-2}, $b=-200\pm100 rad^{-1}$, $c=10\pm3$. The index of refraction of the square plate is 1.46 ± 0.08. From the Residual plot, most data points are within 2 error bars. Hence, this is a good fit.

The accepted value for the index of refraction of plastic is in a range from 1.3010 to 1.7100 [2]. The Chi Squared value = 1.516. The critical value for 99% confidence at 10 degrees of freedom is 2.558. Since $\chi^2_{calc} < \chi^2_{crit}$, this fitted model is statistically acceptable, and there is no significant difference between the observed and fitted-expected data.

Thermal Expansion Coefficient of Aluminium

The initial length (L_0) of the aluminium rod is measured to be 90.64 ±0.01 mm. The power source is set to 6.5V, and the temperature of aluminium is measured every 10 fringes (N). The temperature data is measured as a difference (ΔT) relative to the zero point T_0 = 22.2±0.1℃. N is taken as the independent variable as its uncertainty (±1) is assigned arbitrarily based on our confidence in our ability to reproduce the fringe count for the same ΔT. The data is expressed in figure 3, and is fit to the equation

$$N \simeq \frac{2L_0}{\lambda}\alpha\Delta T \qquad (3)$$

where N is the independent variable and ΔT is the dependent variable (Appendix 1.3). N is taken as the independent variable as its uncertainty (±1) is assigned arbitrarily based on our confidence in our ability to reproduce the measurements. The gradient of this linear function is ($2\alpha L_0/\lambda$), measured to be *0.130±0.001K.* The thermal expansion coefficient of Aluminium is determined to be $22.5\times10^{-6}\pm0.2\times10^{-6}$ K^{-1} (Appendix 2.3).

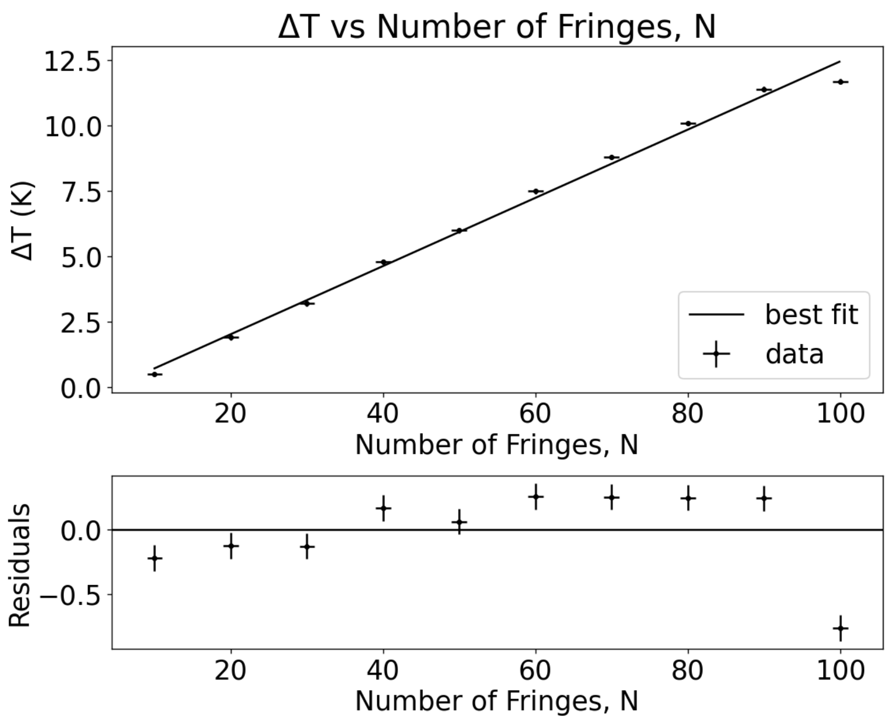

Figure 4. Graph of the number of fringes (N) against increase in temperature (ΔT) of the rod. The coefficients of the quadratic best fit line (y=mx+b) are m=0.130±0.001K, b= -059±0.07K The thermal expansion coefficient of Aluminium is determined to be $22.5\times10^{-6}\pm0.2\times10^{-6}$ K^{-1}. From the Residual plot, most data points are within 2 error bars. Hence, this is a good fit.

The accepted value for the thermal expansion coefficient of Aluminium is $23.8\times10^{-6}K^{-1}$ [3]. The Chi squared value = 1.115, while the critical value for 99% confidence at 8 degrees of freedom is 1.646. Since $\chi^2_{calc} < \chi^2_{crit}$, this fitted model is statistically acceptable, and there is no significant difference between the observed and fitted-expected data.

4 Discussion and Conclusion

The purpose of this experiment was to apply the concept of wave interference to determine three properties – the wavelength of the green laser, the index of refraction of plastic, and the thermal expansion coefficient of Aluminium.

The wavelength of the green laser was calculated to be 620 ± 40nm, which is accurate to 16.5% of the accepted value (532nm ± 1nm). The major sources of error are conflicting interference patterns due to reflection of the light beams, the laser operating over a range of wavelengths, and systematic error in counting fringes. In the future, to minimize these errors, accuracy in apparatus alignment can be increased, and smudges in the aiming and movable mirrors can be cleaned. Furthermore, multiple repetitions of the same number of fringes can be counted by different people and a mean of the values can be used to reduce the effect of anomalous entries.

The index of refraction of the plastic square plate was calculated to be 1.46 ± 0.08, which is within the range of index of refraction values of plastics. The major sources of error is inaccuracy in fringe count and angle measurement. To increase accuracy in the angle measurement, multiple trials for the same fringe count can be taken and analysed. To increase accuracy in fringe count, the movable mirror knob can be turned to zoom further into the fringe pattern and increase clarity in the fringes while counting.

The thermal expansion coefficient of Aluminium was calculated to be $22.5\times10^{-6}\pm0.2\times10^{-6}\ K^{-1}$, which has a 5.46% difference from the accepted value ($23.8\times10^{-6}K^{-1}$). The major source of error in the thermal expansion coefficient is the inaccuracy in the counting of fringes. To reduce this, the voltage of the power source can be set lower, so that fringes appear slower and hence are easier to count.

5 References

[1] Thorlabs, “CPS532-C2 - Collimated Laser-Diode-Pumped DPSS Laser Module, 532 nm, 0.9 mW, Round Beam, Ø11 mm Housing”, [Online]. Available: https://www.thorlabs.com/thorproduct.cfm?partnumber=CPS532-C2. Accessed: Nov. 21, 2025

[2] Scientific Polymer Products, Inc., “Refractive Index of Polymers by Index”, SciPoly Technical Library, [Online]. Available: https://scipoly.com/technical-library/refractive-index-of-polymers-by-index/. Accessed: Nov. 21, 2025

[3] P. Hidnert, “Thermal Expansion of Aluminium and Various Important Aluminium Alloys”, NBS Scientific Paper 697, Scientific Papers of the Bureau of Standards, vol 19, [Online]. Available: https://nvlpubs.nist.gov/nistpubs/scientificpapers/nbsscientificpaper497vol19_a2b.pdf. Accessed Nov. 21, 2025

6 Appendix

1. Data Tables

1.1 Raw Data for Wavelength of Green Laser

Number of fringes (N)	Uncertainty in N (ΔN)	Change in distance (Δx) [μm]	Uncertainty in change in distance ($\Delta\Delta x$)[μm]
50	1	17.0	0.7
40	1	13.0	0.7
30	1	8.0	0.7
39	1	13.0	0.7
16	1	6.0	0.7
40	1	12.0	0.7
40	1	14.0	0.7
37	1	9.0	0.7
40	1	13.0	0.7
19	1	6.0	0.7
40	1	11.0	0.7
39	1	12.0	0.7
39	1	11.0	0.7

1.2 Raw Data for Index of Refraction

Number of Fringes (N)	Uncertainty in N (ΔN)	Change in angle (θ) [degrees]	Uncertainty in Change in angle ($\Delta\theta$) [degrees]
15	1	2.28	0.08
20	1	3.14	0.08
60	1	6.93	0.08
10	1	2.17	0.08
25	1	4.00	0.08
30	1	4.81	0.08
40	1	5.36	0.08
50	1	6.47	0.08

1.3 Raw Data for Thermal Expansion Coefficient of Aluminum

Zero Point, $T_0 = 22.2 \pm 0.1$ °C
Initial Length of the Aluminum Rod, $L_0 = 90.64 \pm 0.01$ mm

Temperature (T) [°C]	Uncertainty in Temperature (ΔT) [°C]	Number of Fringes (N)	Uncertainty in N (ΔN)
22.7	0.1	10	1
24.1	0.1	20	1
25.4	0.1	30	1
27.0	0.1	40	1
28.2	0.1	50	1
29.7	0.1	60	1
31.0	0.1	70	1
32.3	0.1	80	1
33.6	0.1	90	1
33.9	0.1	100	1

2. Error propagation calculations

Percentage error = $\left|\frac{Accepted - Experimental}{Accepted}\right| \times 100$

Error propagation for graph 1 (Δx vs N)

- $\Delta x = x_f - x_i$
- $\Delta(\Delta x) = \sqrt{(\Delta x_i)^2 + (\Delta x_f)^2}$

From the graph, $m = \frac{\lambda}{2}$

- $\Delta\lambda = \Delta m$

Error propagation for graph 2 (N vs θ)

- $\Delta\theta = \theta_f - \theta_i$

From the graph, $a = \frac{t}{\lambda}(1 - \frac{1}{n})$

- $\Delta(a\lambda) = a\lambda\sqrt{(\frac{\Delta a}{a})^2 + (\frac{\Delta\lambda}{\lambda})^2}$
- $\Delta(1 - \frac{a\lambda}{t}) = (1 - \frac{a\lambda}{t})\sqrt{(\frac{\Delta(a\lambda)}{a\lambda})^2 + (\frac{\Delta t}{t})^2}$
- $\Delta n = (\frac{1}{1-\frac{a\lambda}{t}})^{-2}\Delta(1 - \frac{a\lambda}{t})$

Error propagation for graph 2 (N vs θ)

- $\Delta T = T_f - T_i$
- $\Delta(\Delta T) = \sqrt{(\Delta T_i)^2 + (\Delta T_f)^2}$

From the graph, $m = \frac{\lambda}{2\alpha L_0}$

- $\Delta(L_0 m) = L_0 m \sqrt{(\frac{\Delta m}{m})^2 + (\frac{\Delta L_0}{L_0})^2}$
- $\Delta\alpha = (\frac{\lambda}{2L_0 m})\sqrt{(\frac{\Delta\lambda}{\lambda})^2 + (\frac{\Delta L_0 m}{L_0 m})^2}$