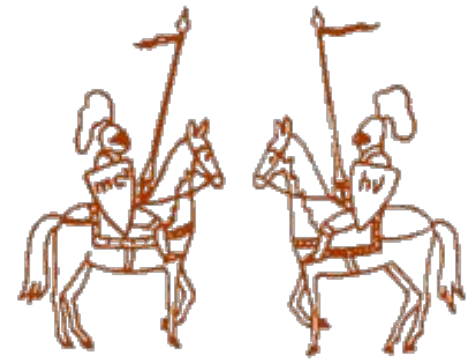




**RUSSIA**

**Problem №9**

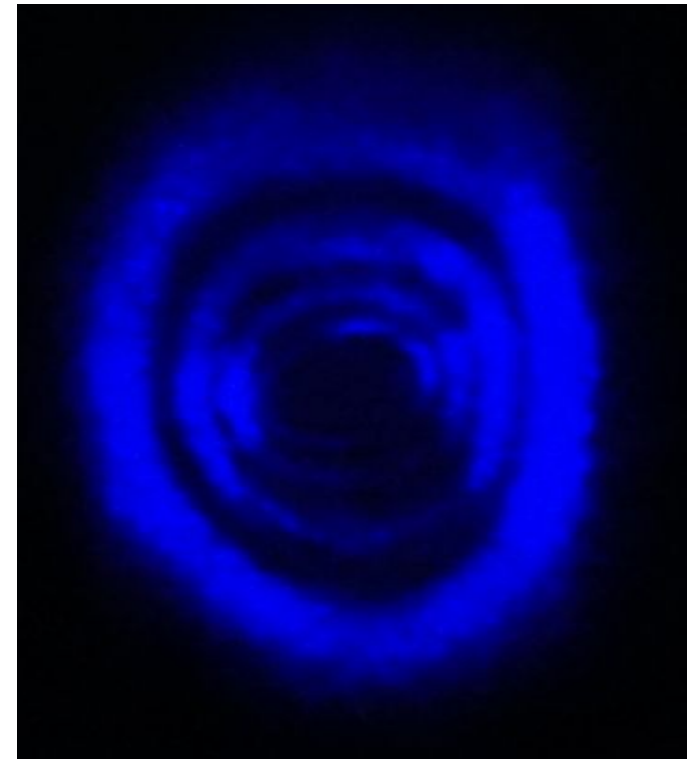


# «Soy sauce optics»

Using a laser beam passing through a **thin layer** (about 200  $\mu\text{m}$ ) of soy sauce the **thermal lens** effect can be observed. Investigate this phenomenon.

**Team Russia**

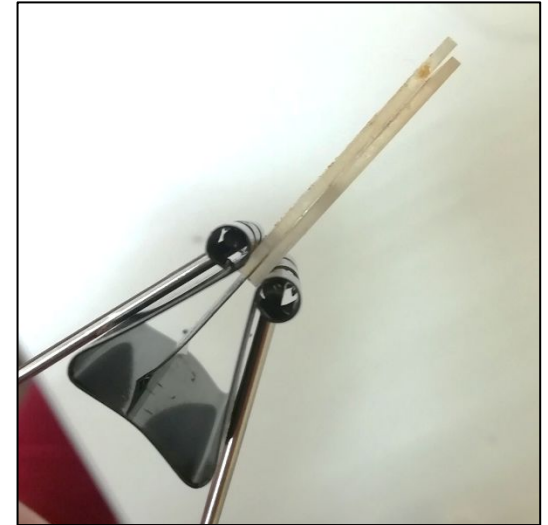
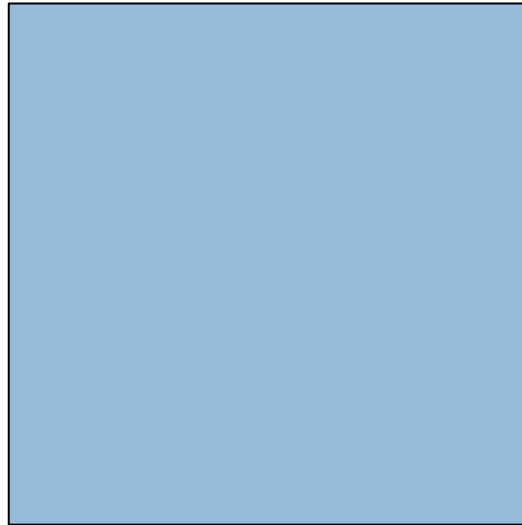
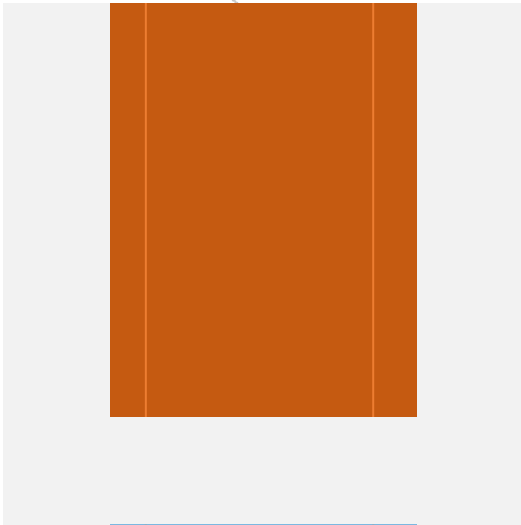
**Reporter: Katerina Zamaraeva**



# 1. Experimental setup



*Distance between glasses -  
from 0.13 to 1mm*



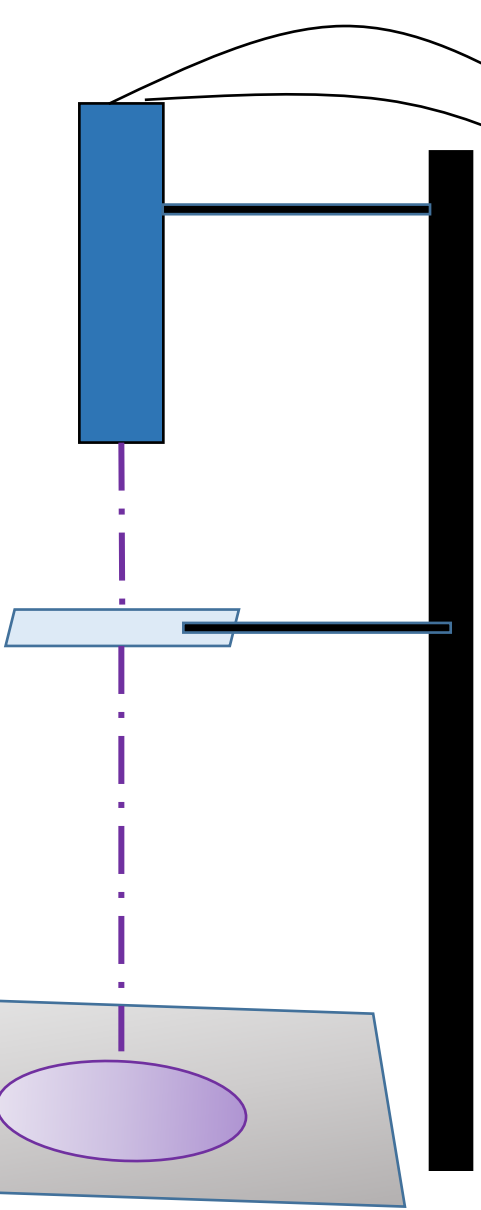
Clamping the  
glasses

# 2. Experimental setup

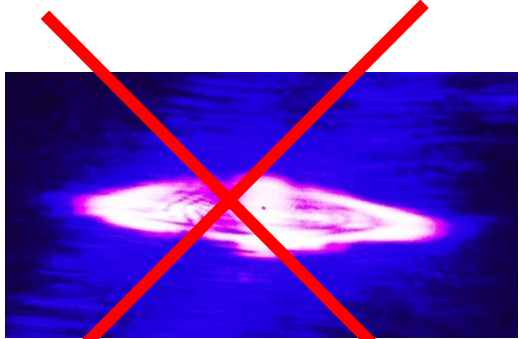
Laser  
Average power-  
1 Watt

Soy lens

Picture



Current source

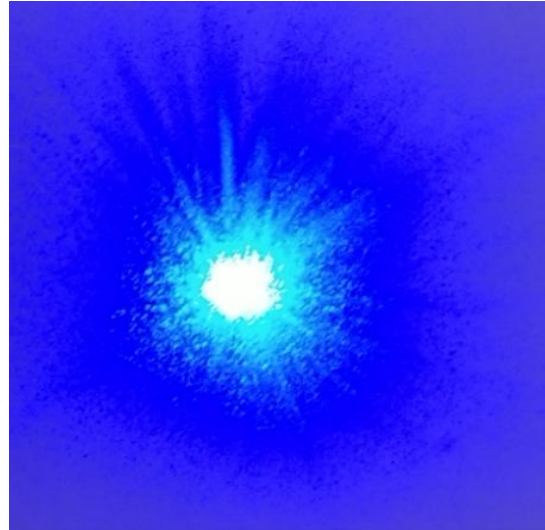


Vertically position  
soy lens

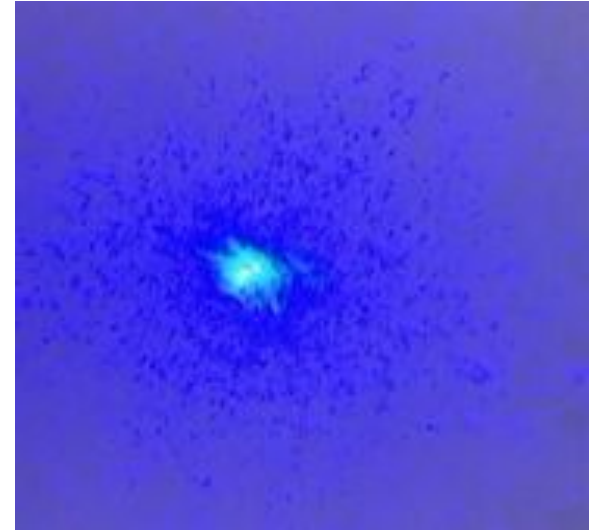
# 1. First observations



Without lens

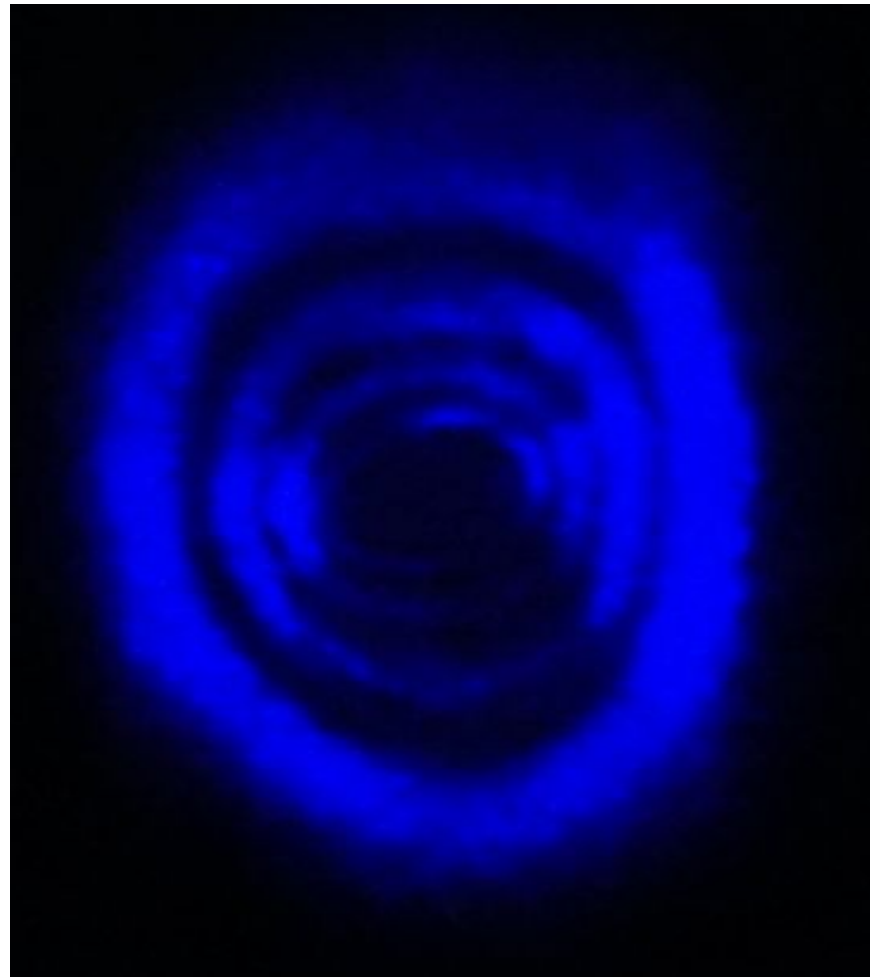


In the beginning  
with lens



After some time

## 2. First observations



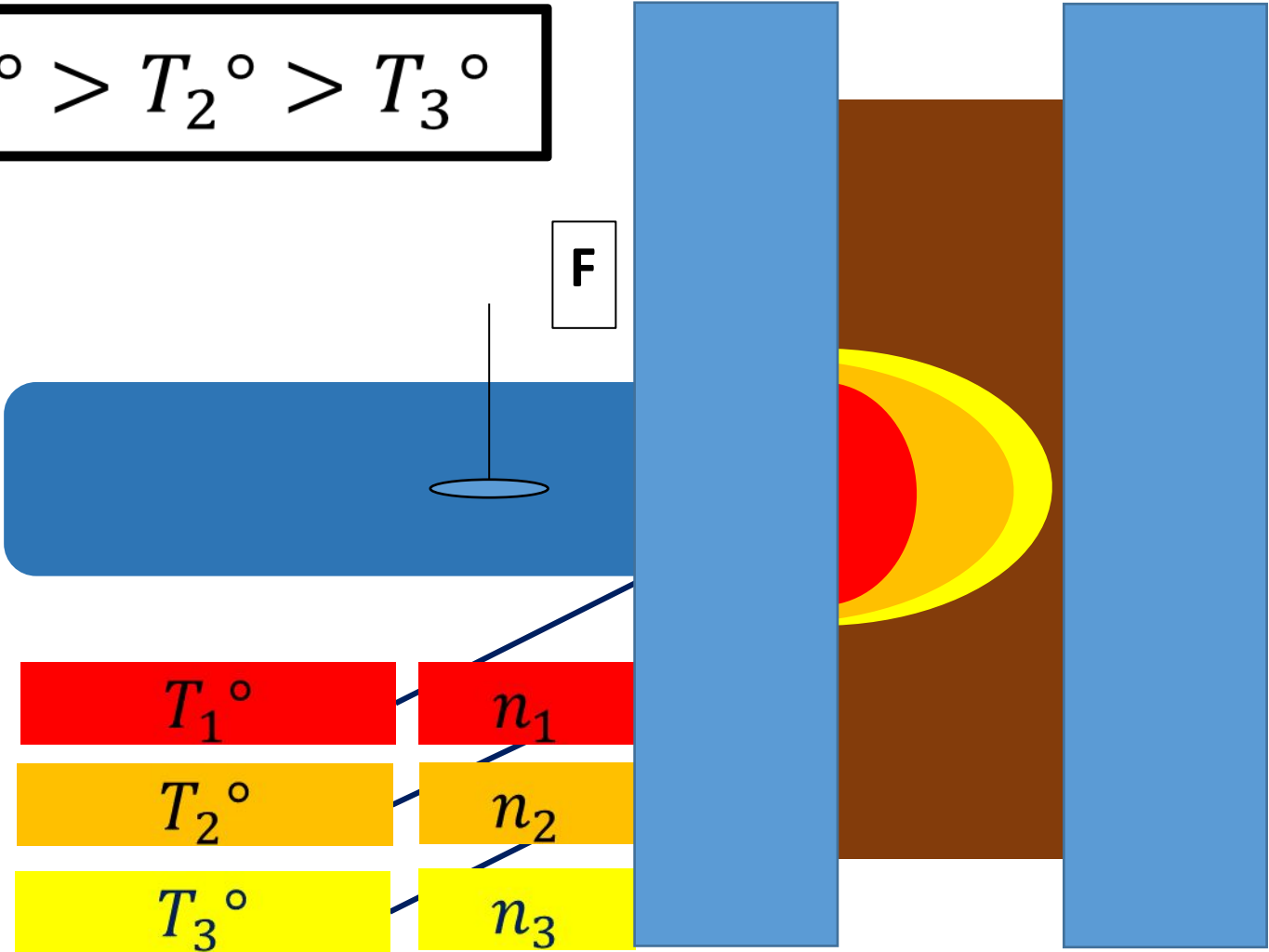
The rings formed

# Main point

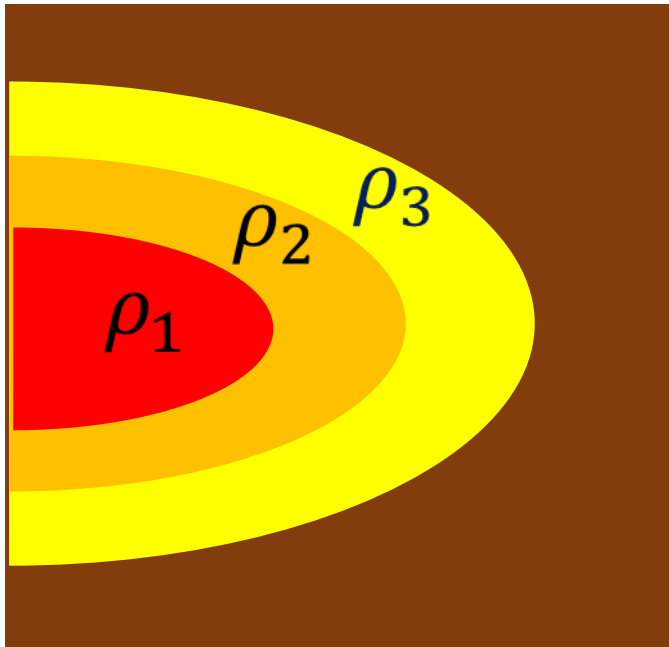
- Absorption

# Qualitative explanation

$$T_1^\circ > T_2^\circ > T_3^\circ$$







Due to thermal expansion of liquids:

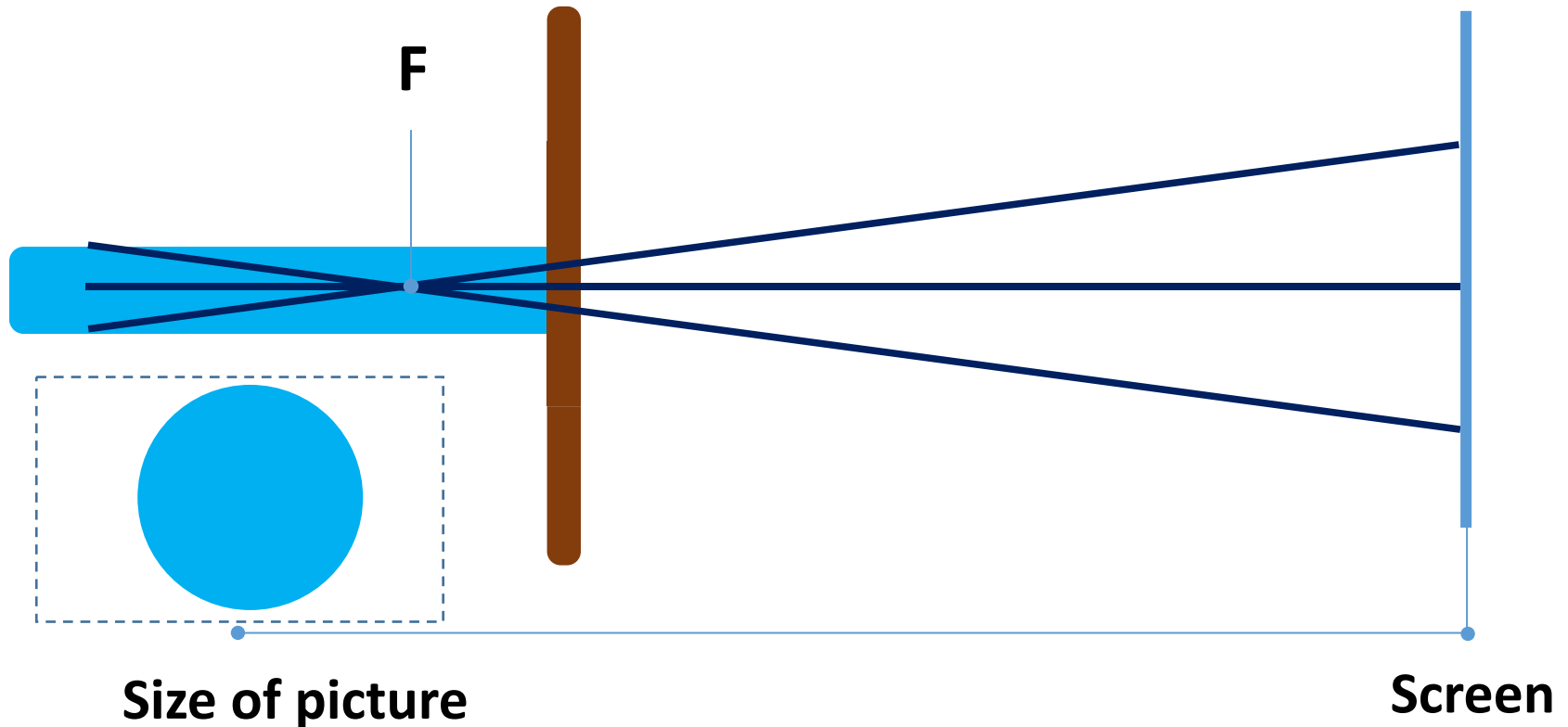
$$\rho_1 < \rho_2 < \rho_3$$

$$n_1 < n_2 < n_3$$

**Rays are deflected to the side with a large refractive index.**

Dispersive lens

# Why image gets smaller?



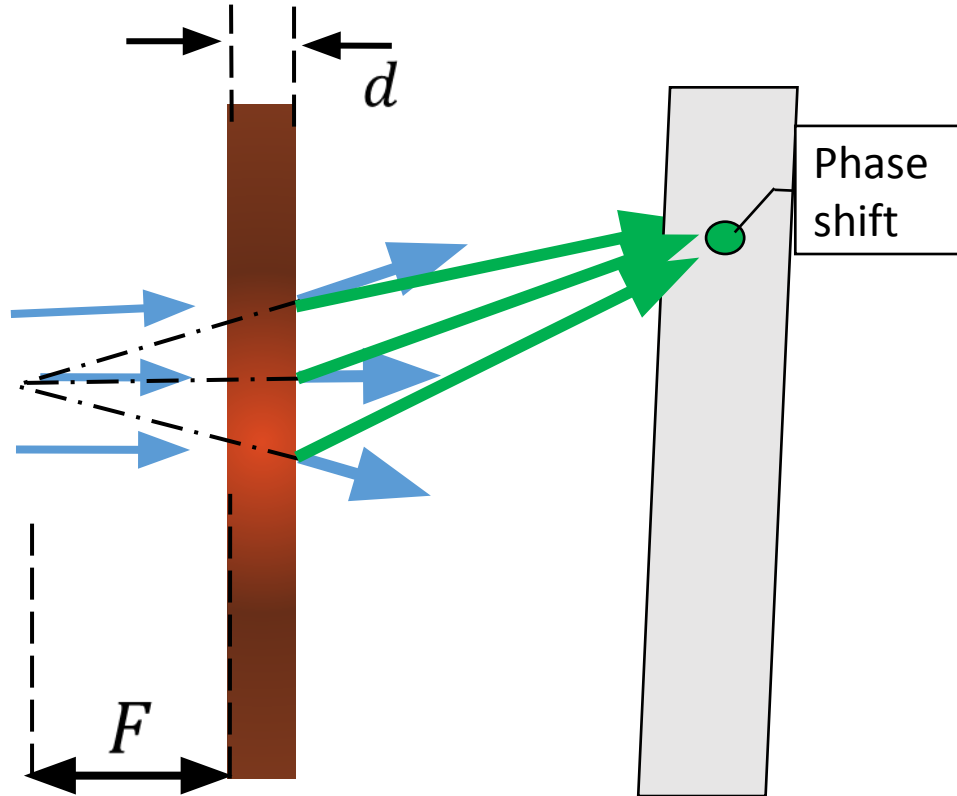
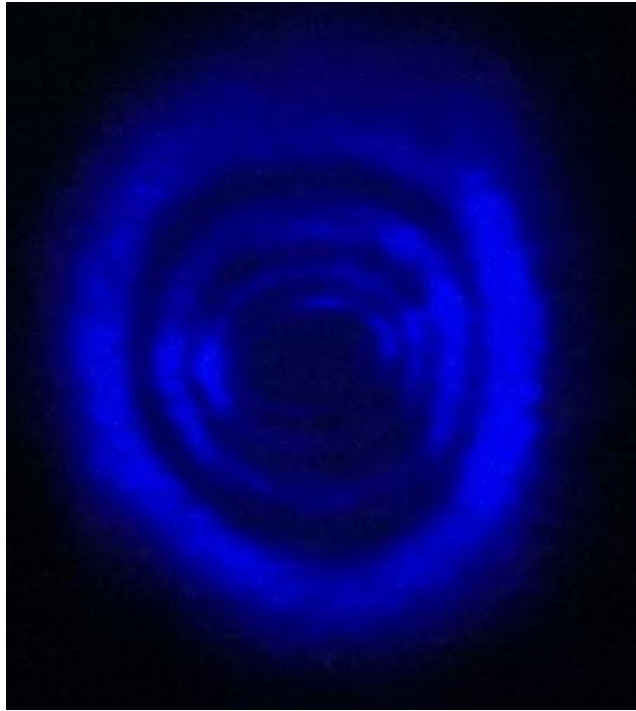
After some time all soy sauce heating

No temperature difference

No change in the refractive index

# Ring formation

$$\varphi(r) = kn(r)r$$

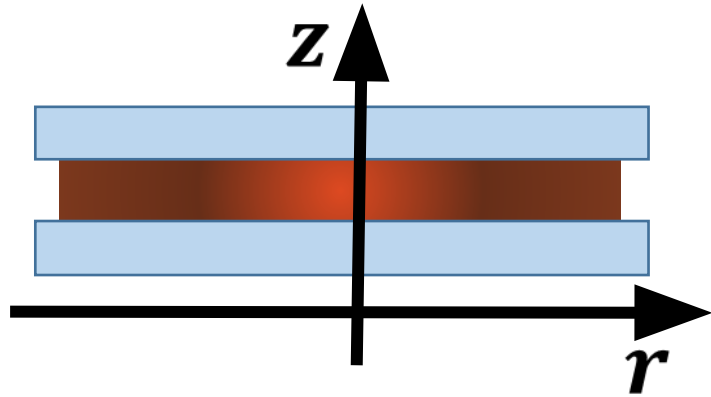


Rays are different distances and changing the reflective index therefore there is a phase shift

Characteris  
tically  
distance  
soy lens-

# Mathematical model

# The temperature distribution



## Heat equation

Heat capacity coefficient

Capacity per unit volume

$$c\rho \frac{\partial T}{\partial t} = \kappa \Delta T + Q(\mathbf{r}, t)$$

Thermal conductivity

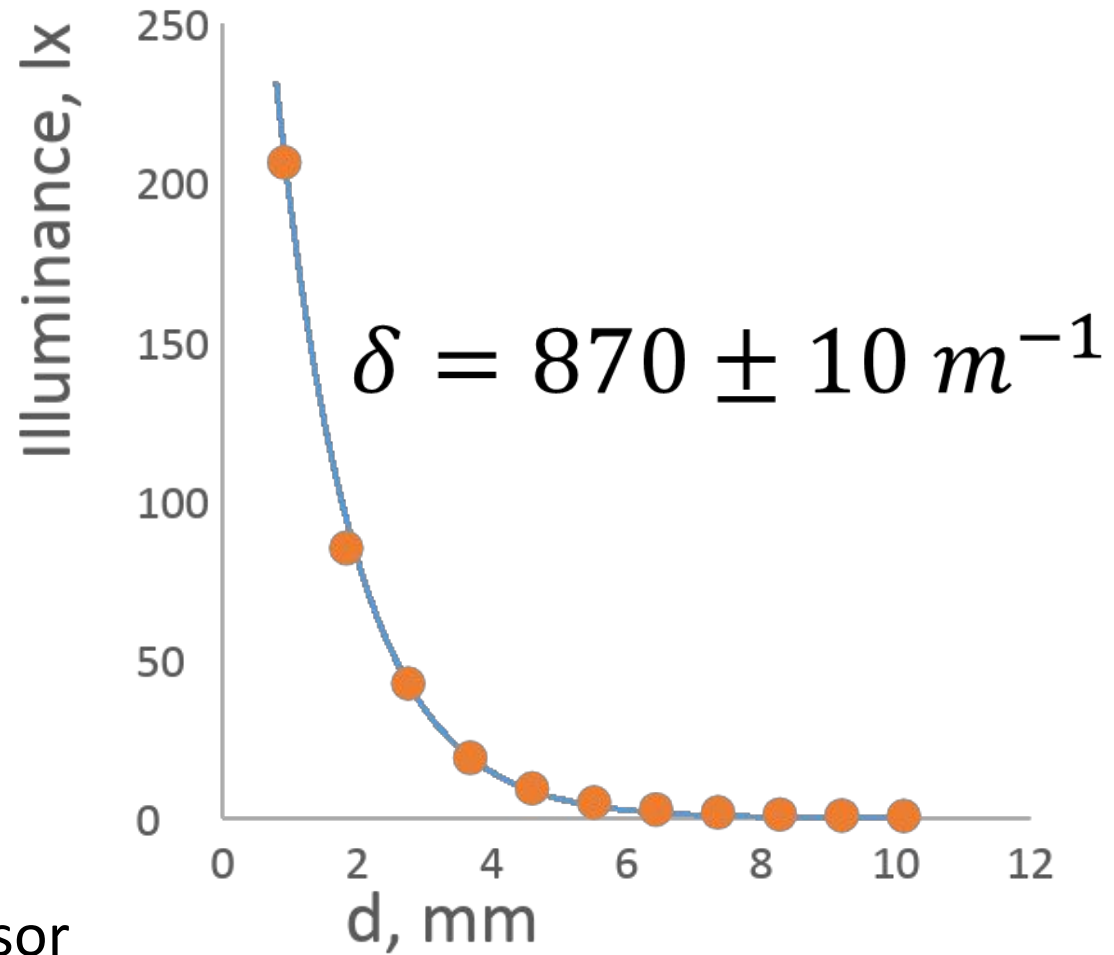
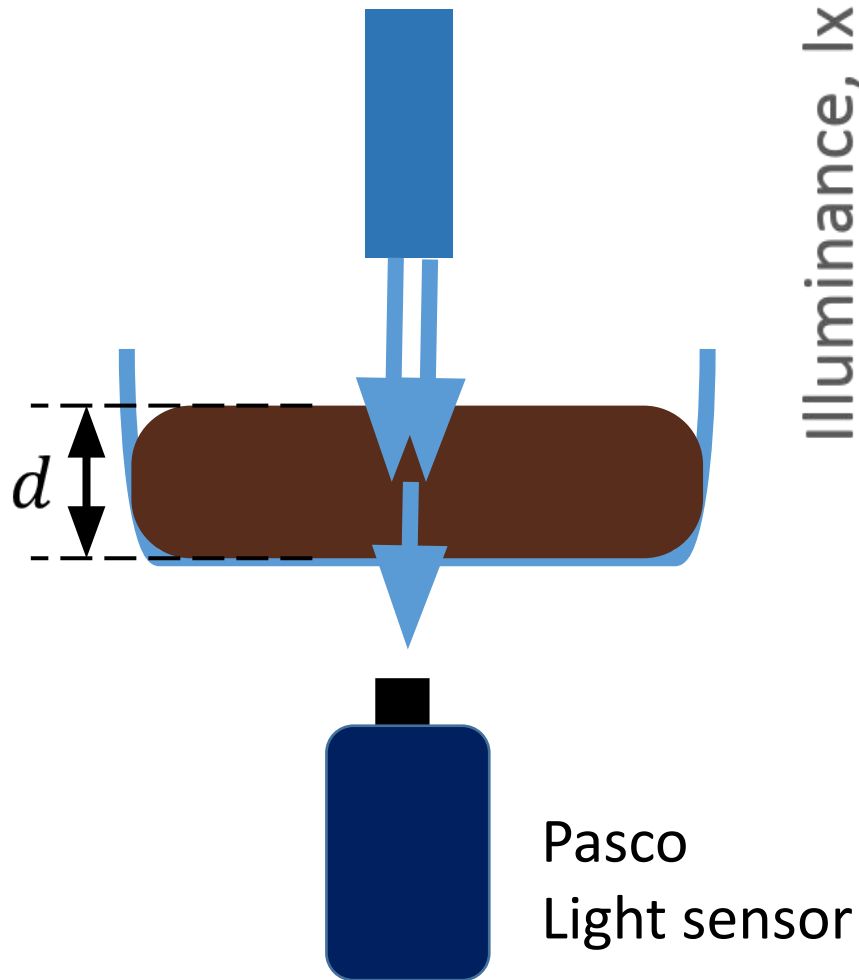
Ray absorption

$$I = I_0 \exp(-\delta z)$$

Intensity

Absorption coefficient

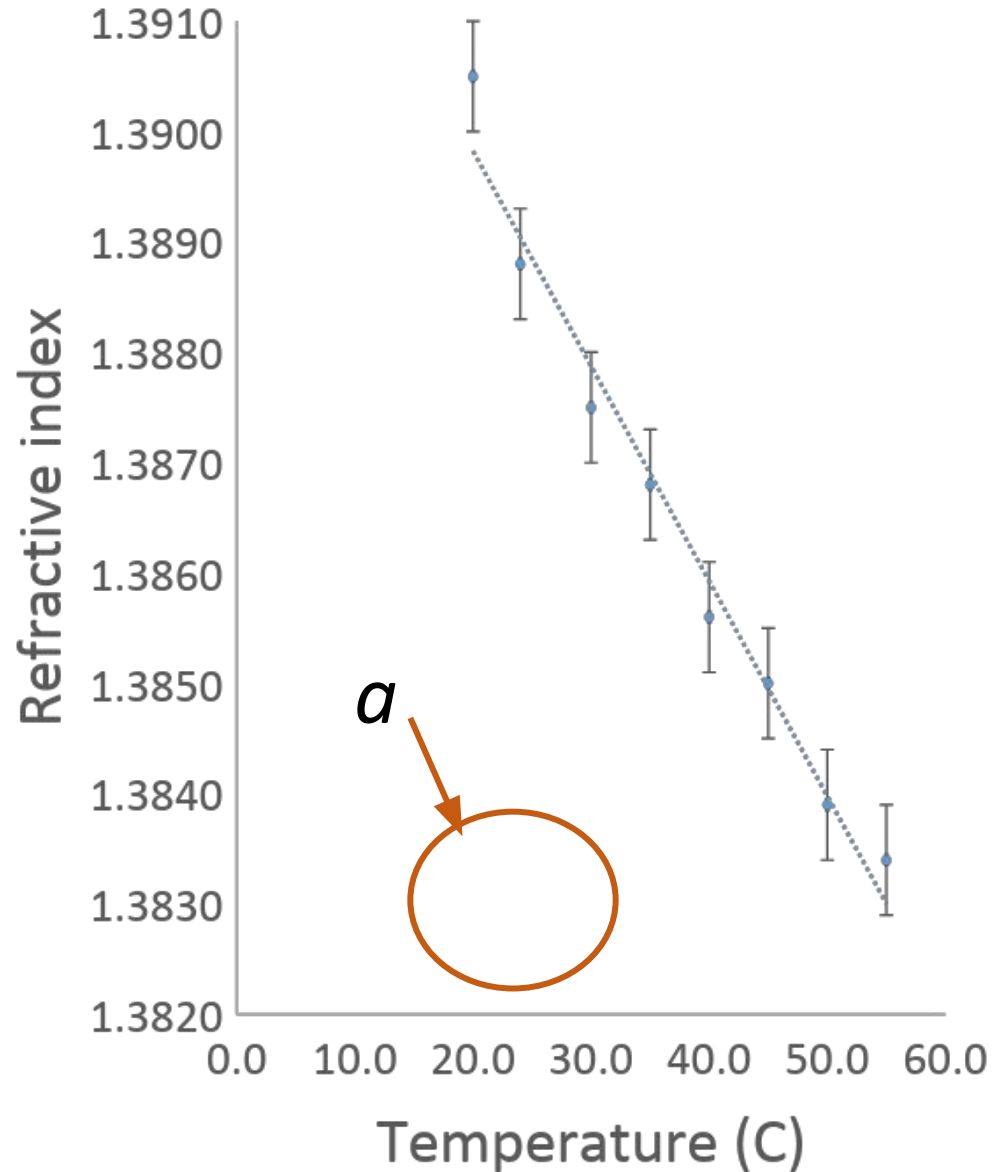
# Absorption coefficient $\delta$ :



# Coefficient- changing reflective index with the temperature

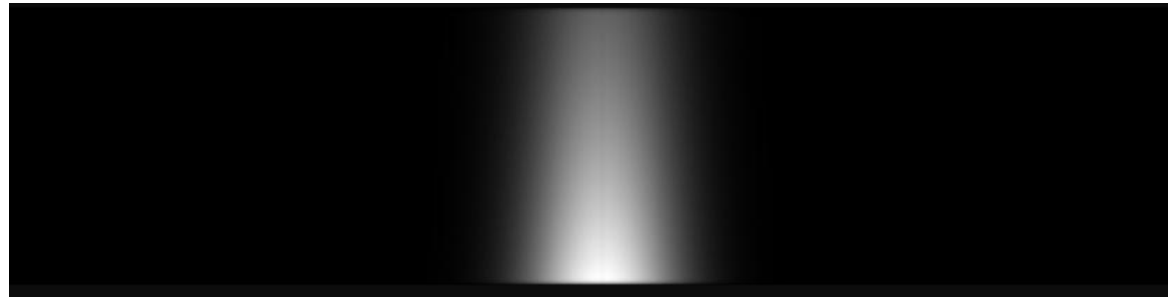


*Refractometer - device measuring the refractive index of light*



$$T = \begin{cases} T_0 + \frac{\delta I_0}{4\kappa} (R^2 - r^2), & r \leq R \\ T_0, & r > R \end{cases}$$

IMPORTA  
NT!

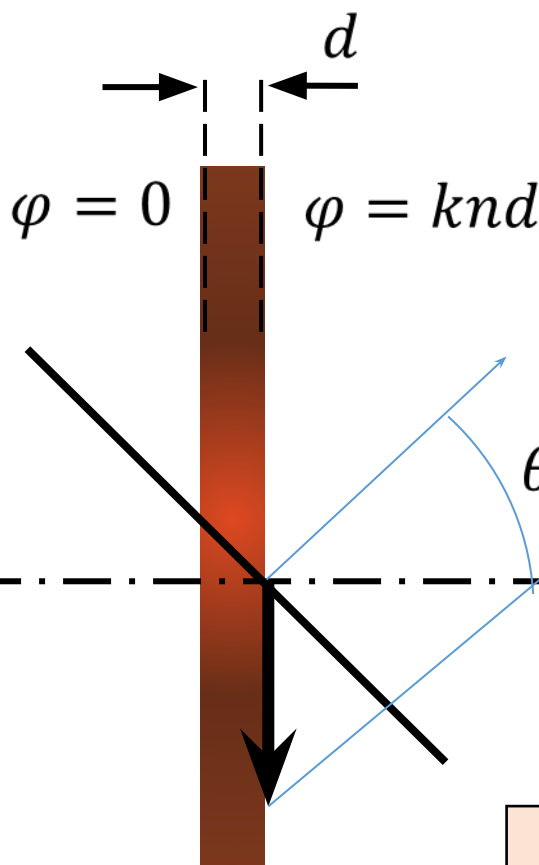


Laser

Program model



# Intensity distribution in the image



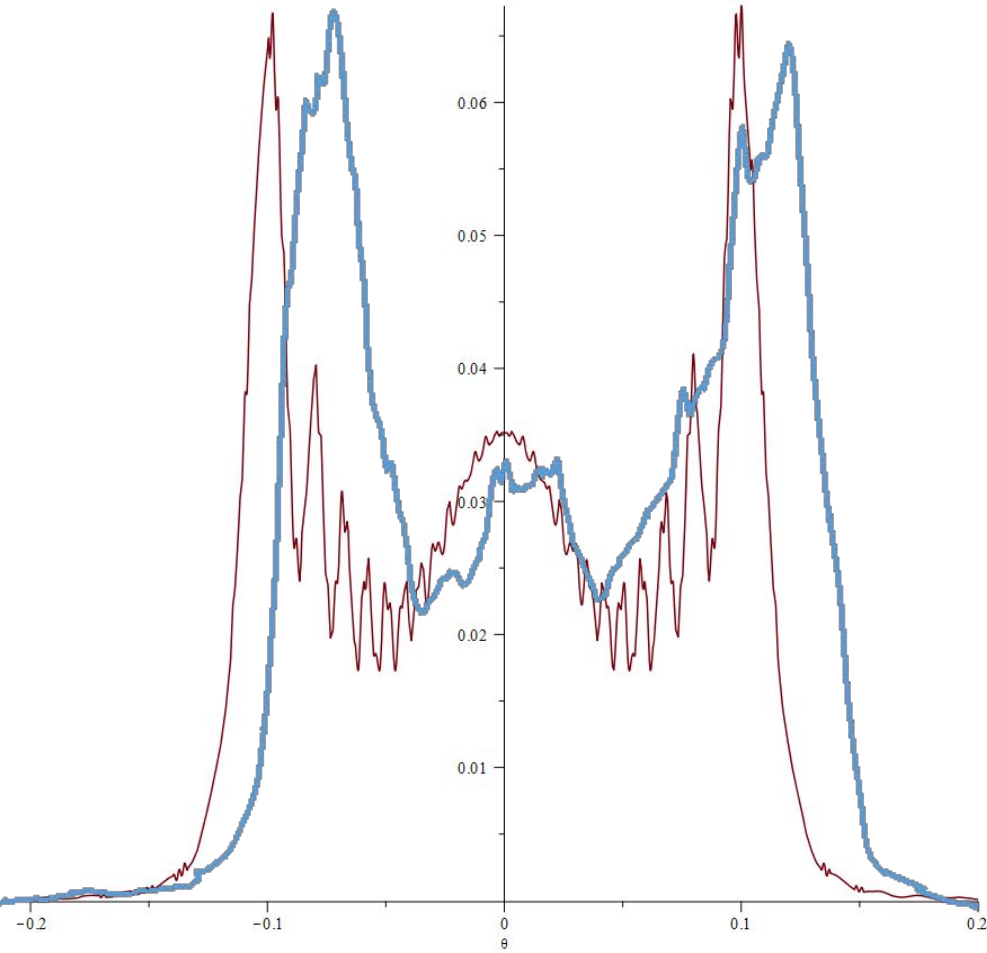
Area element

$$A = A_0 \int_0^R \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} e^{\frac{-1}{2} \frac{r^2}{R^2}} e^{i\varphi} r d\psi dr$$

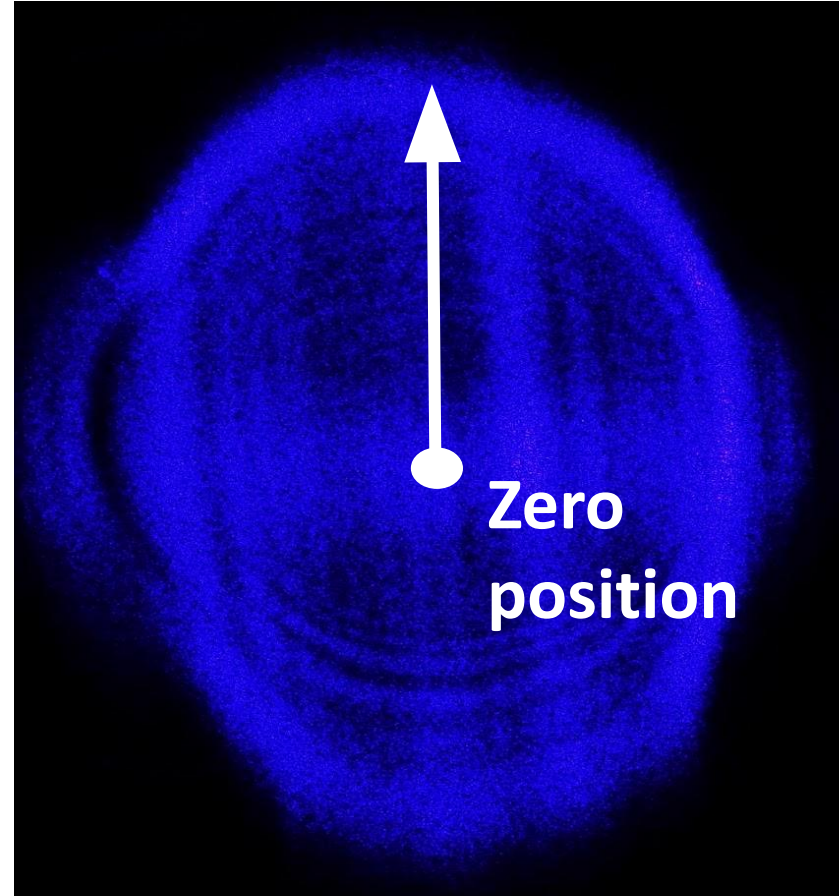
$$\varphi = k(n(r)d + r \sin(\theta) \sin \psi)$$

$$I = I_0 \exp(-\delta z) |A|^2$$

# Theory VS practice

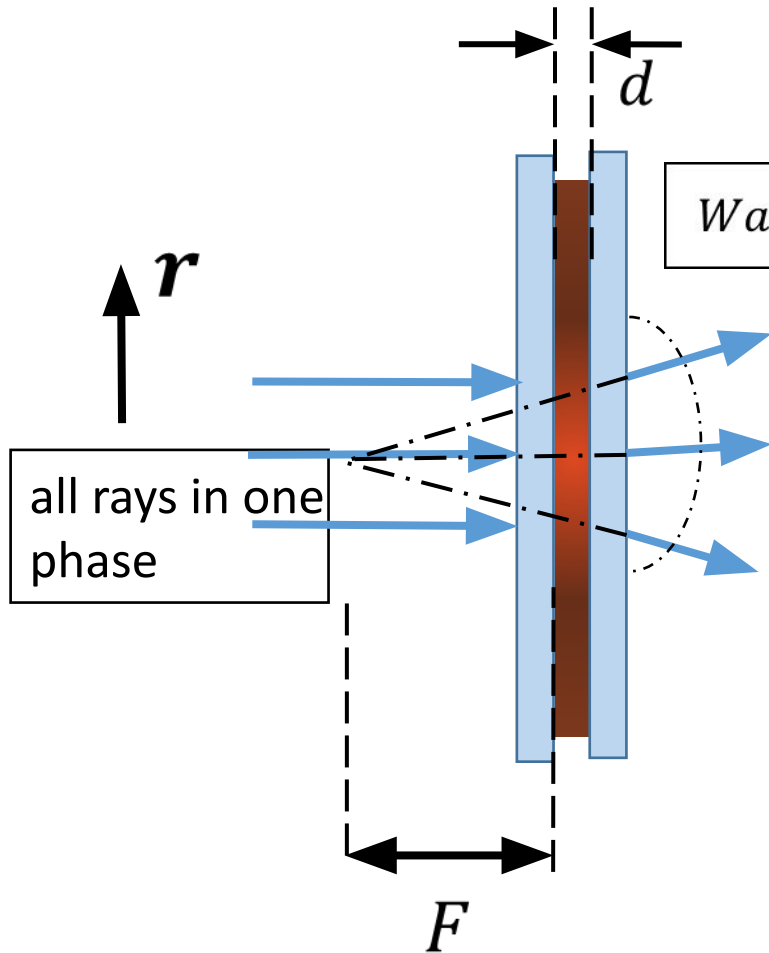


Program Maple VS Practice



Experimental

# Focal length



Refractive index without heating

$$n = n_0(1 + \alpha T) = n_{ex} - \frac{n_0 \alpha \delta I_0}{4\kappa} r^2$$

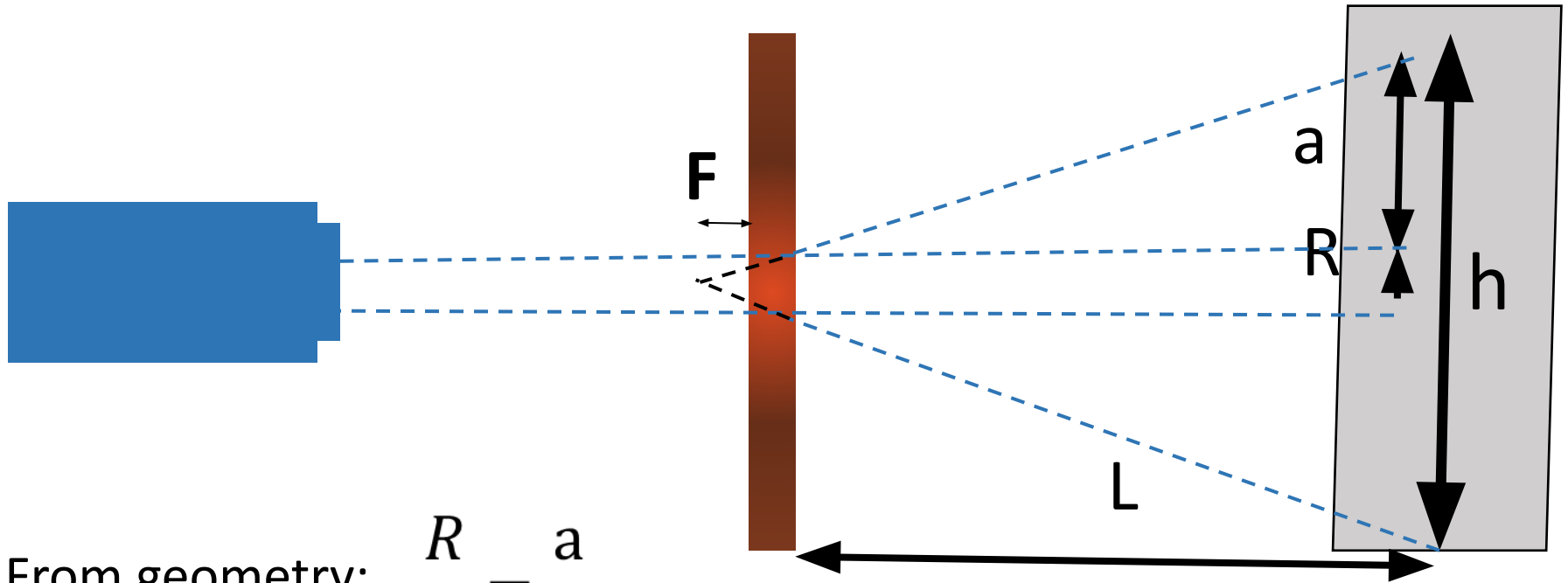
coefficient of thermal conductivity

$$\varphi(r) = kn(r)d + k\sqrt{F^2 + r^2} \approx kn_{ex}d - k\frac{n_0 \alpha \delta I_0 d}{4\kappa} r^2 + kF + \frac{kr^2}{2F}$$

$$\frac{k}{2F} - k\frac{n_0 \alpha \delta I_0 d}{2} = 0$$

$$D = \frac{1}{F} = \frac{n_0 \alpha \delta I_0 d}{2\kappa}$$

# Experimental finding of focal length



From geometry:  $\frac{R}{F} = \frac{a}{L}$

$$h = 2a + 2R$$

$$h = \frac{2LR}{F} + 2R$$

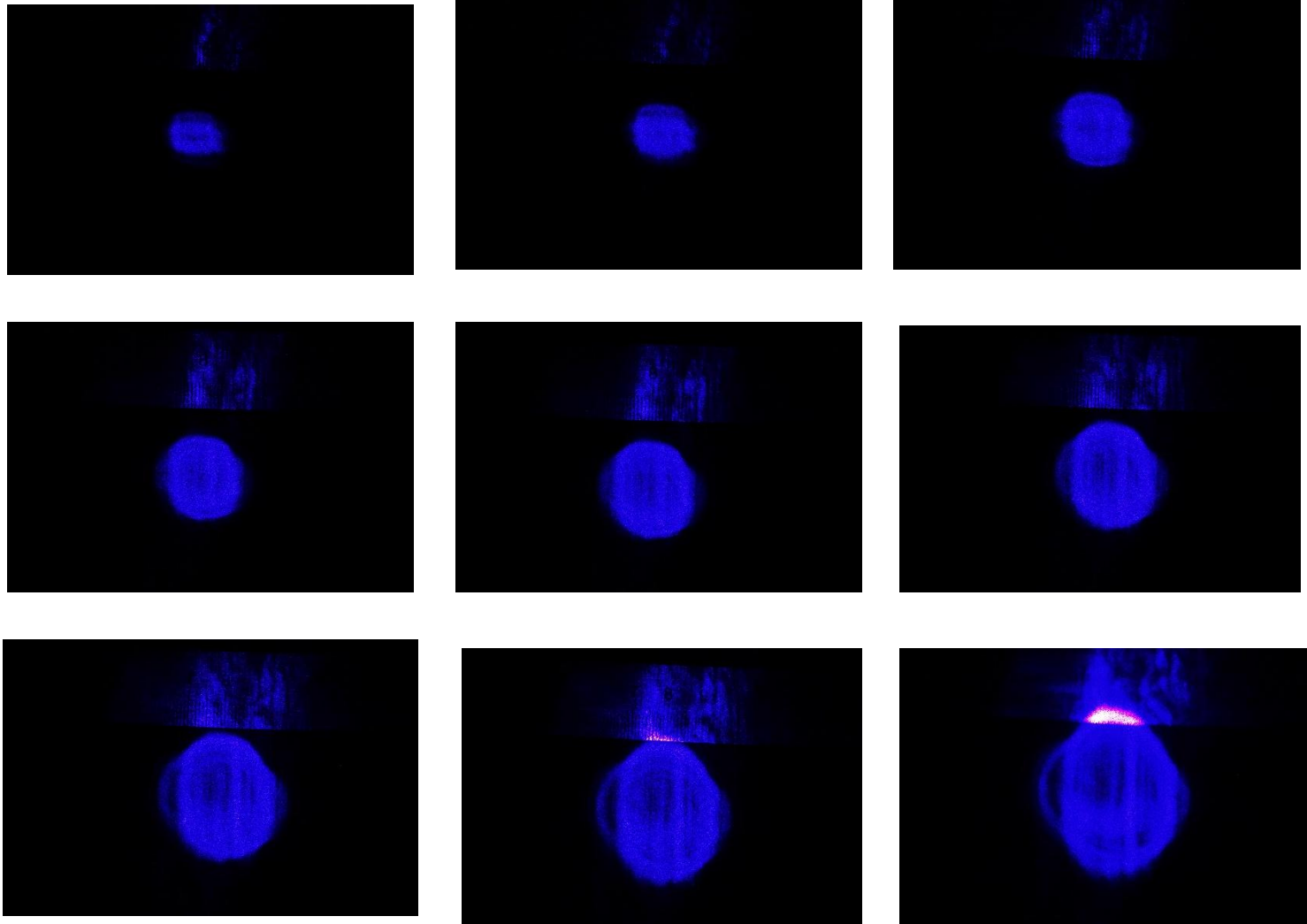
$$F = \frac{2LR}{h - 2R} = \frac{1}{D}$$

# Compeering

$$F = \frac{2LR}{h - 2R} = \frac{1}{D}$$

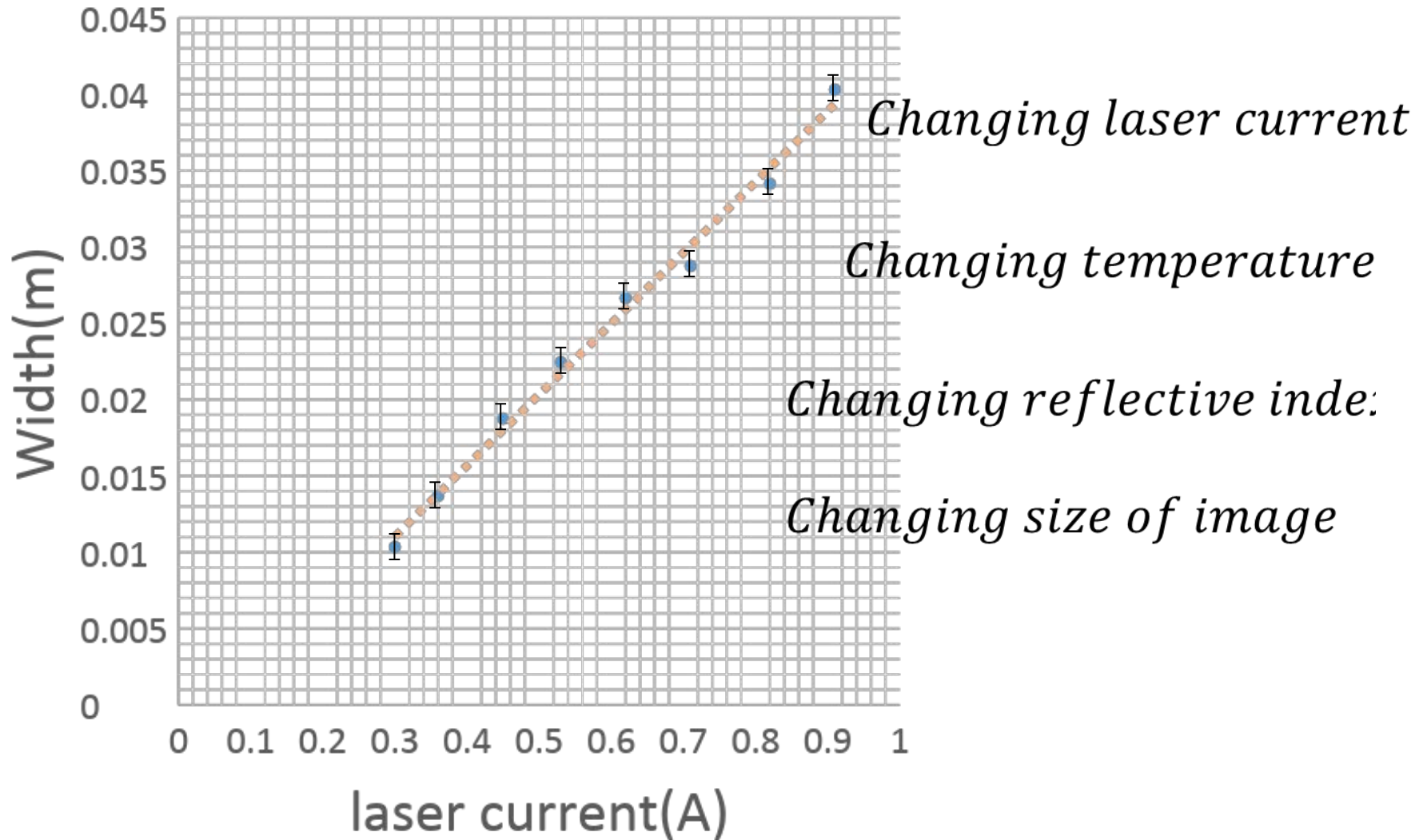
# Parametric studies

# The effect of laser current on image size



With increasing current increases the image

# Image width from laser current





# Optical power VS thickness of soy sauce

$D (m^{-1})$



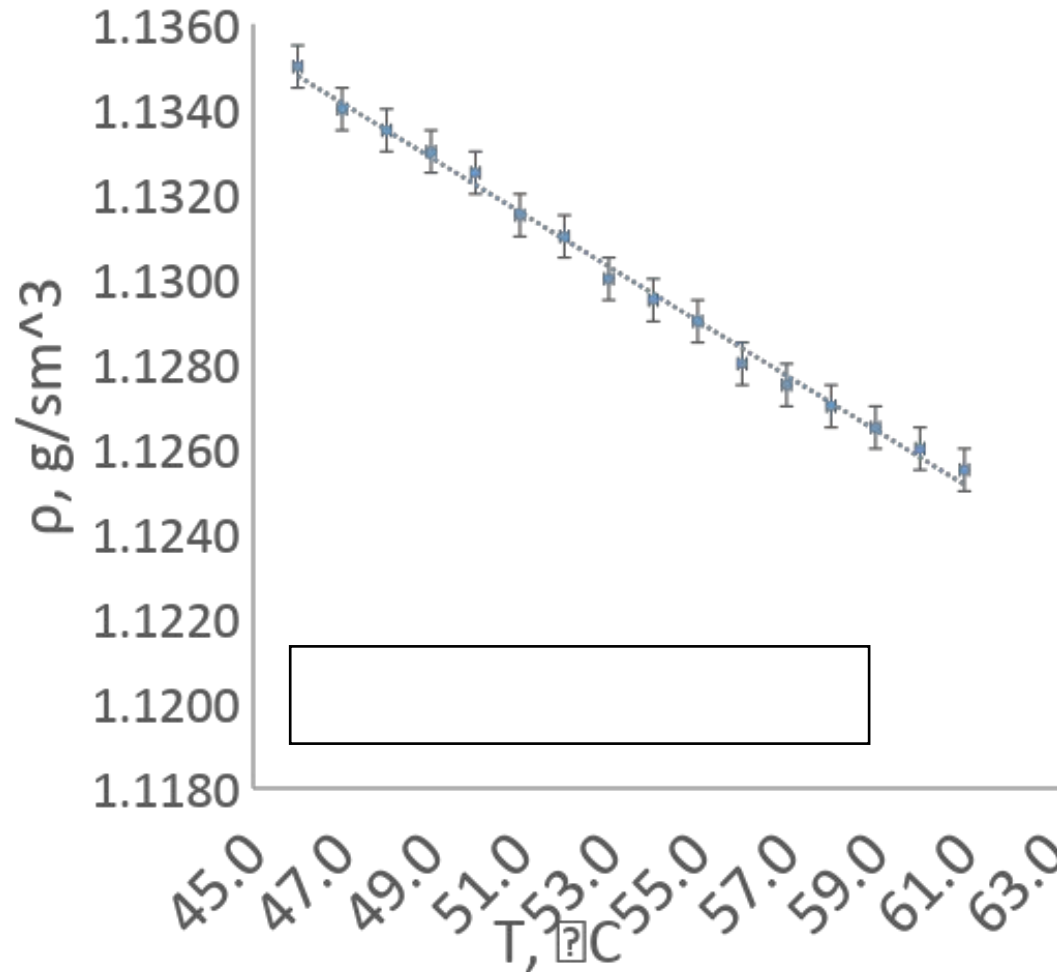
$d (m)$

plate to control  
the height

# Density VS Temperature



*Refractometer*



# Conclusion

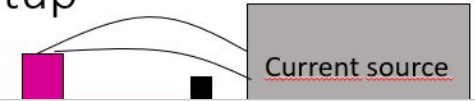
Experimental setup. Laser with constant power

Qualitative explanation (different hitting soy sous, different phase of beam)

Temperature distribution and absorption coefficient

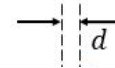
Theoretical formula for focal length and got method for experimental

Experimental setup



Due to thermal expansion of liquids:

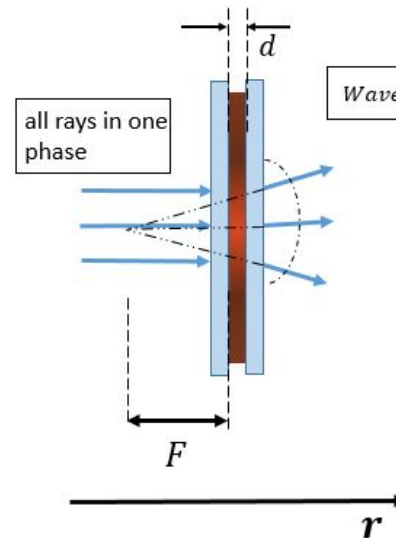
Ring formation



Absorption coefficient  $\delta$ :  
Focal length

$$n = n_0(1 + \alpha T) = n_{ex} - \frac{n_0 \alpha \delta I_0}{4\kappa} r^2$$

Labels: *Refractive index without heating* (pointing to  $n$ ), *coefficient of thermal conductivity* (pointing to  $\kappa$ )



$$\varphi(r) = kn(r)d + k\sqrt{F^2 + r^2} \approx kn_{ex}d - k\frac{n_0 \alpha \delta I_0 d}{4\kappa} r^2 + kF + \frac{kr^2}{2F}$$

$$\frac{k}{2F} - k\frac{n_0 \alpha \delta I_0 d}{2} = 0$$

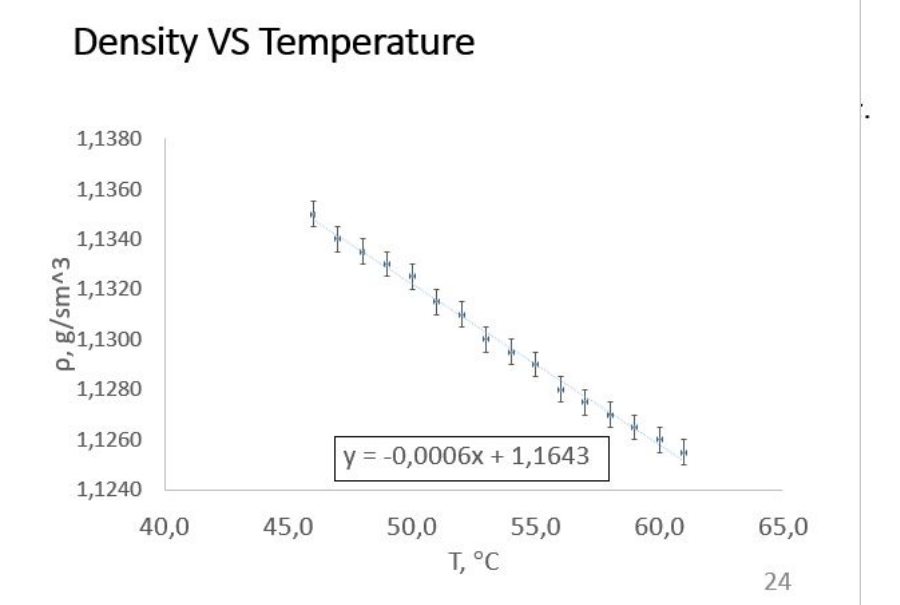
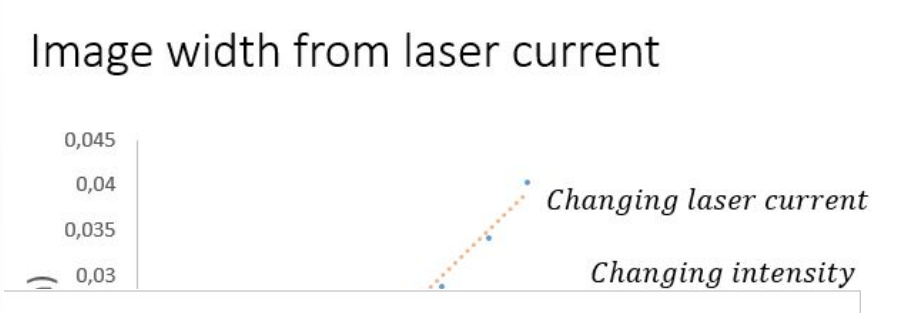
$$D = \frac{1}{F} = \frac{n_0 \alpha \delta I_0 d}{2\kappa}$$

Finding coefficient showing the change reflective index with temperature

Got comparing practice and theory and explain the errors

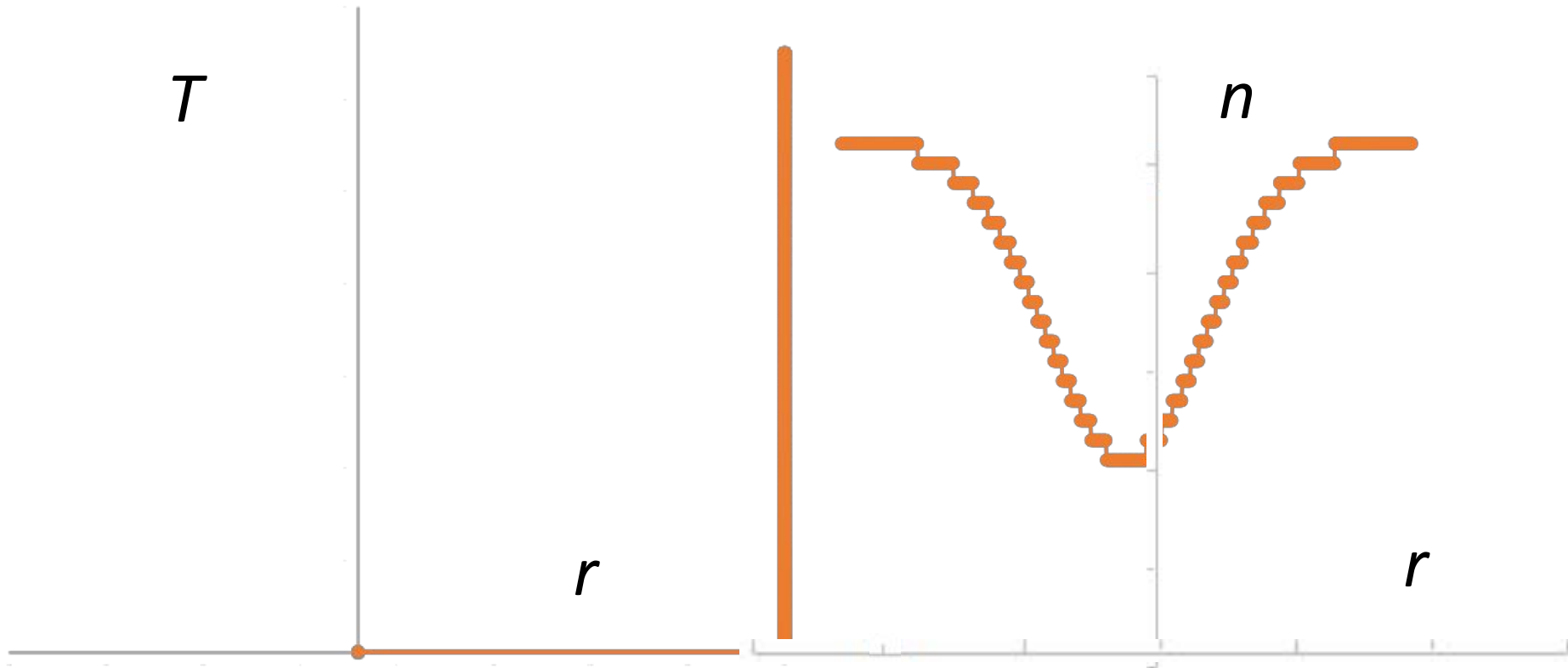
The dependents image width from laser current

Changing density with temperature



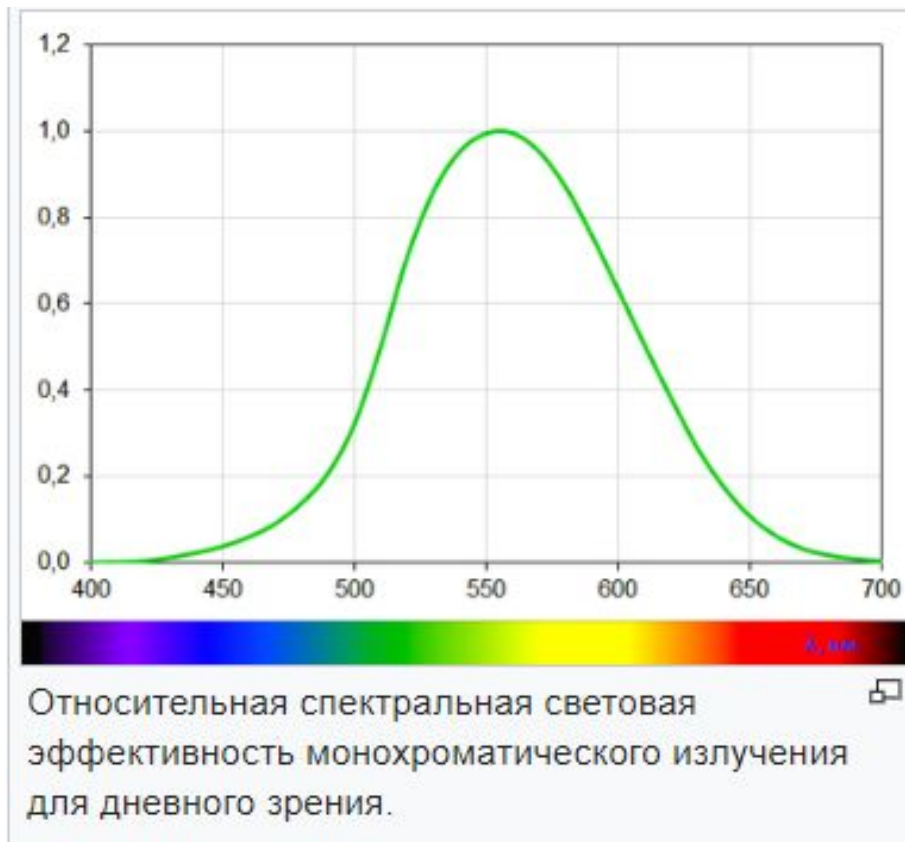


# Qualitative graphs



In the center-maximum temperature and minimum refractive index

# Освещенность

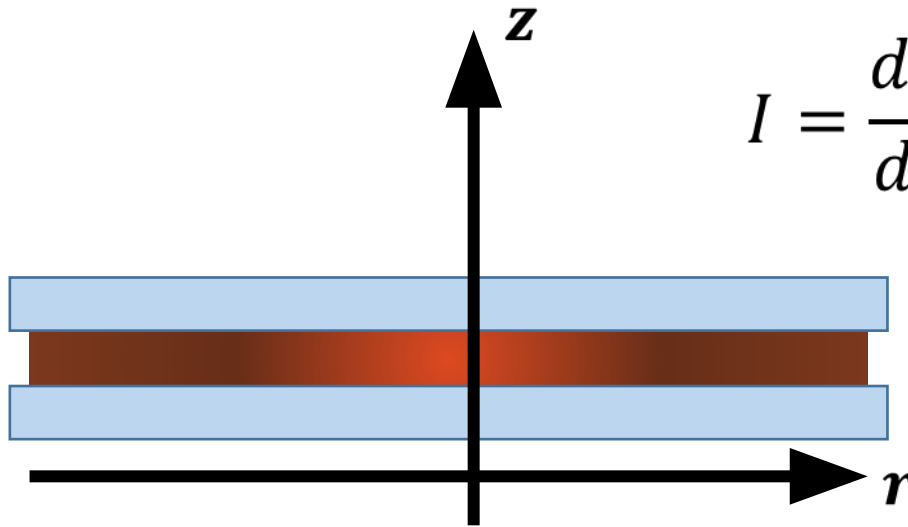


$$\begin{aligned}
n &= n_0(1 + \alpha T) = n_0 \left( 1 + \alpha \left( T_0 + \frac{\delta I_0 d}{4\gamma} R^2 \right) \right) - \frac{n_0 d \alpha \delta I_0}{4\gamma} r^2 \\
&= n_{ex} - \frac{n_0 d \alpha \delta I_0}{4\gamma} r^2
\end{aligned}$$



$$I = I_0 \exp(-\delta z); \quad \delta = \delta(\lambda, T) \approx \delta(\lambda)$$

$$c\rho \frac{\partial T}{\partial t} = \kappa \Delta T + Q(\mathbf{r}, t)$$



$$I = \frac{dP}{dS}$$

$$Q = -\frac{dP}{dV} = -\frac{d}{dz} \left( \frac{dP}{dS} \right)$$

$$= \delta I_0 \exp(-\delta z)$$

$$c\rho \frac{\partial T}{\partial t} = \kappa \Delta T + Q(\mathbf{r}, t) \rightarrow$$

$$\Delta T = \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) + \frac{\partial^2 T}{\partial z^2} + \frac{1}{r} \frac{\partial^2 T}{\partial \varphi^2}$$

$$\Delta T = -\frac{Q(z)}{\kappa} = -\frac{\delta I_0 \exp(-\delta z)}{\kappa}$$

$$\rightarrow \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) + \frac{\partial^2 T}{\partial z^2}$$

$$\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) + \frac{\partial^2 T}{\partial z^2} = - \frac{\delta I_0 \exp(-\delta z)}{\kappa}$$

В приближении  $\delta h \ll 1$ ,  $\exp(-\delta z) \approx 1$ ,  $\frac{\partial^2 T}{\partial z^2} \approx 0$

$$\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) = - \frac{\delta I_0}{\kappa}, r \leq R$$

$$\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) = 0, r > R$$

$T(r)$  непрерывна

## СПЕКТР ВИДИМОГО СВЕТА ПО ДЛИНЕ ВОЛНЫ

Цвет	Диапазон длин волн, нм	Диапазон частот, ТГц
Фиолетовый	380—440	790—680
Синий	440—485	680—620
Голубой	485—500	620—600
Зелёный	500—565	600—530
Жёлтый	565—590	530—510
Оранжевый	590—625	510—480
Красный	625—740	480—405

Laser 450 нм

- Стекло 1,52

# Перевод из люксов в СИ

200 люкс = 0.00002928257686676 ватт на кв. см (при 555 нм)

\* 5/7

# • ХАРАКТЕРИСТИКА ДАТЧИКА




PASPort™

## Light Sensor

PS-2106A



### Sensor Specifications

Sensor Ranges:	 0-2.6 lux
	 0-260 lux
	 0-26,000 lux
Accuracy	Better than $\pm 1$ db of max value of selected range
Resolution:	0.01% of max value of selected range
Max Sample Rate:	1,000 sps
Default Sample Rate:	5 sps
Operating Temperature	0-40°C

## Light Sensor Quick Start

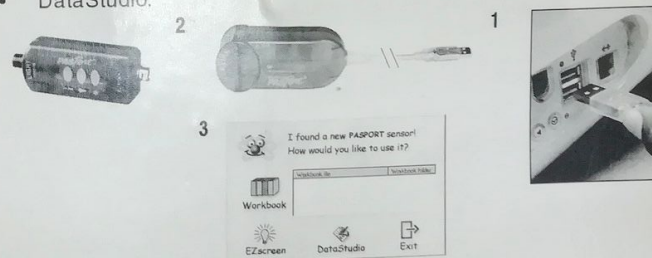
The PS-2106 Light Sensor measures illuminance in units of lux.

### Additional Equipment Needed

- PASPORT Link Device (USB Link, Xplorer, etc.)
- EZscreen or DataStudio™ software (version 1.5 or later)

### Equipment Setup

1. Connect the PASPORT Link Device to a USB port on your computer or USB hub.
2. Connect the sensor to a PASPORT Link Device.
3. The software launches when it detects a PASPORT sensor. From the PASPORTAL screen, select a point of entry:
  - an activity in the Workbook window,
  - EZscreen, or
  - DataStudio.



PASCO®

800-772-8700 • 916-786-3800 • techsupp@pasco.com • www.pasco.com

012-09835A