Institute of Physics
Centre for Science and Education
Silesian University of Technology

Physics laboratory report

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Exercise 6: Determining the temperature dependence of the viscosity coefficient of liquids with the Höppler viscometer

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Introduction

Experimental set-up

The figure depicts a cross-section of a Höppler viscometer, which is used to measure the viscosity of liquids. The measurement involves determining the time it takes for a steel ball to descend through a measuring tube filled with paraffin oil. The measuring tube is surrounded by a water jacket, into which water is pumped and heated or cooled using an ultrathermostat. The temperature of the paraffin oil is measured using a mercury decimal thermometer. The L vial and the adjustment screws in the base are used to set up the instrument properly. The water jacket, together with the measuring tube, can rotate around the O axis, and the Z latch holds the system in the measuring position. The measuring tube is closed with metal plugs that have rubber valves to prevent damage during heating. Three scratches are etched on the measuring tube, and it is recommended that the falling time be measured for the extremes of the cracks. The ball's passage through the crack can be referred to the upper or lower limit of the ball. The measurement is performed with the pipe blocked. Heating of the water constituting the water jacket is carried out by an ultrathermostat equipped with a pump.

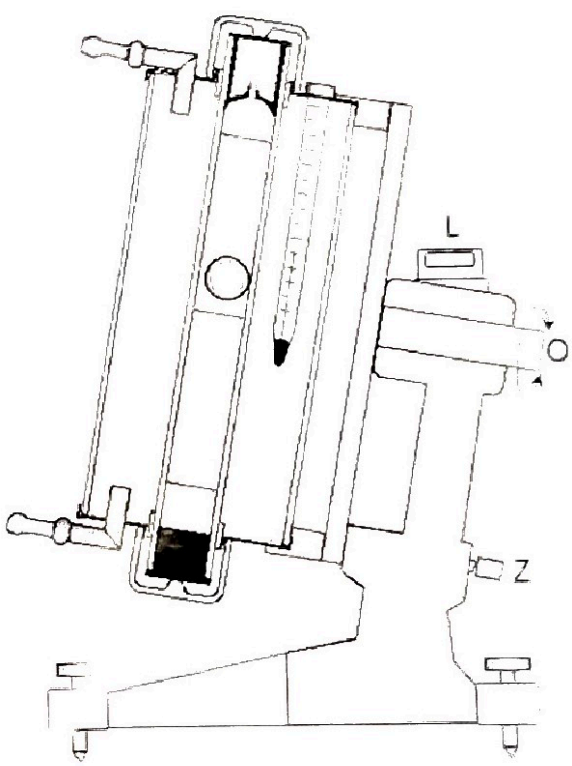

Figure 1 - measurement set-up used during laboratories.

Measurements

No.	Temp $(^{\circ}C)$	Fall time(s) 1	2	3
1.	26	2.14.6	2.13	2.13.3
2.	30	1.44.9	1.43.9	1.39.6
3.	35	1.23	1.21.1	1.18.4
4.	40	1.05.5	1.02.5	1.01.5
5.	45	0.51	0.49	0.48.9

Table 1 - Data obtained during laboratories.

Data analysis

Task 1. Calculate the average values of the ball's fall time t.

To calculate the average value of times we used formula:

$$\bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i \ [s]$$

The results were placed into the table.

Temperature $^{\circ}C$	$\bar{t}\ [\frac{m}{s}]$
26	133.6333
30	102.8000
35	80.8333
40	63.1667
45	49.6333

Table 2 - Average fall times for each temperature.

Task 2. Calculate the statistical uncertainty $u_a(t)$ for a series of time measurements (standard deviation, multiplied by the corresponding Fisher's Student coefficient).

To obtain the statistical uncertainty we used formula:

$$u_a(t) = k\sigma$$

where:

- $k = 2.353$ - Fisher's Student coefficient read from table
- σ - standard deviation calculated using:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})^2}$$

After performing calculations we placed results into the table.

Temperature $^\circ C$	$u_a(t)\ [\frac{m}{s}]$
26	0.4528
30	4.3472
35	3.3057
40	2.2642
45	0.9962

Table 3 - Table with uncertainties of ball's fall times for each temperature.

Task 3. Calculate the total uncertainty of fall times $u(t) = \sqrt{u_a^2(t) + u_b^2(t)}$.

Temperature $^\circ C$	$u(t)\ [\frac{m}{s}]$
26	0.4529
30	4.3472
35	3.3057
40	2.2642
45	0.9963

Table 4 - total uncertainties for each temperature

Task 4. For each temperature, calculate the viscosity coefficient of paraffin oil, using the empirical formula

$$\eta = K(\rho_k - \rho)\bar{t}$$

where:

- $K = 1.2018 \cdot 10^{-6} \frac{m^2}{s^2}$ - apparatus constant
- $\rho_k = 8150 \frac{kg}{m^3}$ - density of the steel ball
- ρ - the density of paraffin oil at different temperatures

Temperature $^{\circ}C$	Viscosity coefficient $[P \cdot s]$
26	1.1683
30	0.8992
35	0.7074
40	0.5530
45	0.4348

Table 5 - viscosity coefficients for each temperature

Task 5. Using the law of uncertainty propagation, calculate the standard uncertainty of all viscosity coefficients.

To obtain proper solution we used:

$$u_{standard}(t) = \sqrt{\frac{\partial \eta}{\partial t} u_a(t)} = \sqrt{K(\rho_k - \rho) u_a(t)}$$

Temperature $^{\circ}C$	Viscosity coefficient uncertainty $[P \cdot s]$
26	0.0629
30	0.1950
35	0.1701
40	0.1408
45	0.0934

Table 6 - Uncertainties of viscosity coefficient for each temperature.

Task 6. Make a graph of the dependence of the viscosity coefficient of paraffin oil on temperature. Plot the uncertainty bars for each measurement point on the graph.

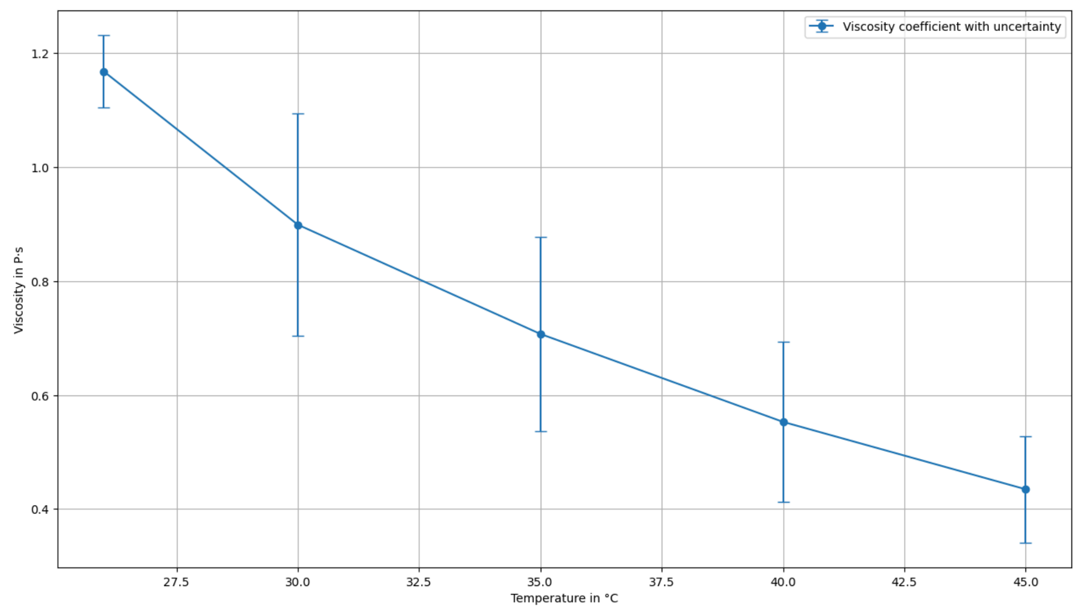

Figure 2 - Plot of the dependence of the viscosity coefficient of paraffin oil on temperature

Task 7. Plot the dependence of the natural logarithm of the viscosity coefficient on the inverse of the temperature expressed in kelvins $ln(\eta) = f(\frac{1}{T})$.

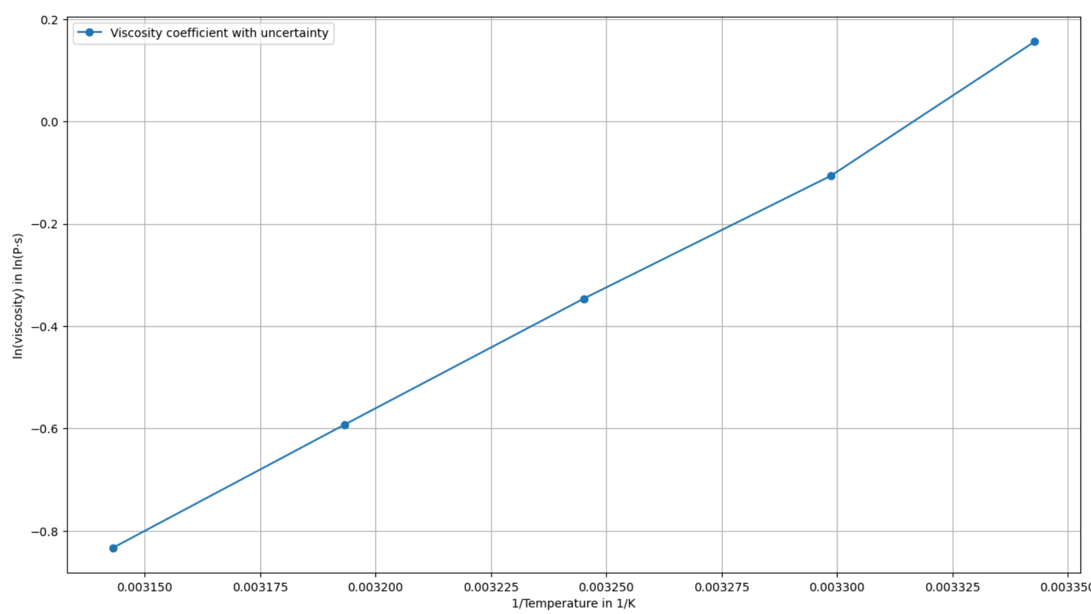

Figure 3 - Plot of the dependence of the natural logarithm of the viscosity coefficient on the inverse of the temperature.

Task 8. Use the linear regression method to fit a straight line. Record the regression coefficients in the appropriate format, with units.

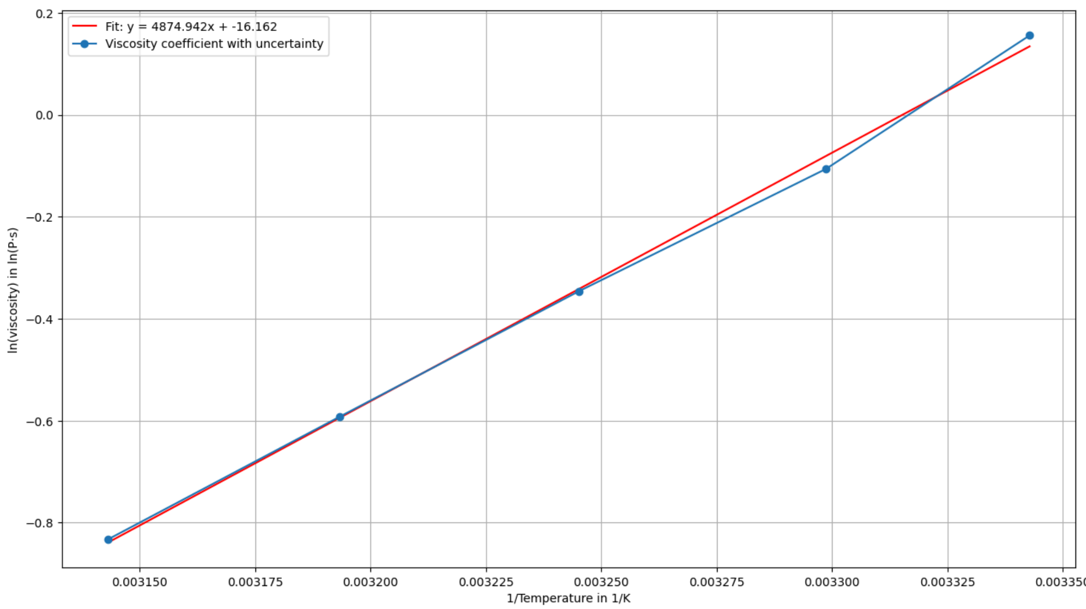

Figure 4 - Plot with fitted line

The parameter a (slope) is equal to 4874.9416 and b (intersect) is equal to -16.1619.

Task 9. Calculate the regression coefficients $b = ln(A)$ and $a = \frac{W}{k}$ (along with uncertainties) of the relationship describing the temperature dependence of the viscosity coefficient

$$\eta(T) = Ae^{\frac{W}{kT}}$$

where:

- $k = 1.38 \cdot 10^{-23} \frac{J}{K}$ - Boltzmann's constant
- W - Viscous flow activation energy for paraffin oil.

after calculations for each temperature we putted results into the table:

Temperature $^{\circ}C$	Regression coefficient
26	1.1435
30	0.9223
35	0.7105
40	0.5519
45	0.4321

Table 7 - Regression coefficients for each temperature.

Task 10. Calculate the activation energy of viscous flow W (express it in J and in eV).

To get activation energy of viscous flow we performed such calculations:

- To obtain results in $Joules$:

$$E_{a_1} = -ak_b \left[J\right]$$

- to obtain result in $electronvolts$:

$$E_{a_2} = \frac{E_{a_1}}{1.602 \cdot e^{-19}}$$

where:

- a - slope parameter
- k_b - Boltzmann constant equal to $1.38 \cdot 10^{-23} \left[\frac{J}{K}\right]$

After putting numbers into equations we obtained the activation region equal to:

$$E_{a_1} = -6.7274 \cdot e^{-20} \ J$$
$$E_{a_2} = -0.4199 \ eV$$

Task 11. Using the law of uncertainty propagation, calculate the standard uncertainty of viscous flow activation energy for paraffin oil.

To obtain the propagated uncertainty we used formula:

$$u_{activation\ region}(t) = \left| -k_b \cdot u_{slope}(t) \right|$$

where:

- $k_b = 1.38 \cdot 10^{-23} \frac{J}{K}$ - Boltzmann's constant
- $u_{slope}(t)$ - standard error of the slope equal to 123.4159.

The $u_{slope}(t)$ was obtained using python script presented below:

```
from scipy.stats import linregress
import matplotlib.pyplot as plt
import math

def task_8(temperatures, viscosity):
    ln_viscosity = [math.log(x) for x in viscosity]
    temps_kelvin = [x + 273.15 for x in temperatures]
    inverse_temps = [1 / T for T in temperatures_kelvin]
    slope, intercept, r_value, _ , stderr = linregress(inverse_temperatures, ln_viscosity)
    plt.errorbar(inverse_temps, ln_viscosity, fmt='-o', label='Viscosity coefficient')
    fit_line = [slope * x + intercept for x in inverse_temperatures]
    plt.plot(inverse_temperatures, fit_line, 'r-', label=f'Fit: y = {slope}x + {intercept}')
    plt.xlabel('1/Temperature in 1/K')
    plt.ylabel('ln(viscosity) in ln(P·s)')
    plt.grid(True)
    plt.legend()
    plt.show()
    return slope, intercept, stderr
```

In this function we are obtaining the slope, intercept and standard error (`stderr`) of the fitted line which we used in our calculations.

Finally after placing numbers into equations we obtain:

$$u_{activation\ region_1}(t) = 1.7031e^{-21} J$$
$$u_{activation\ region_2}(t) = 0.0106\ eV$$

Task 12. Write the result and its uncertainty in the appropriate final notation separately in units of J and eV.

Viscosity Coefficients:

- $26°C$: $\eta = 1.1683 \pm 0.0629\, Ps$
- $30°C$: $\eta = 0.8992 \pm 0.1950\, Ps$
- $35°C$: $\eta = 0.7074 \pm 0.1701\, Ps$
- $40°C$: $\eta = 0.5530 \pm 0.1408\, Ps$
- $45°C$: $\eta = 0.4348 \pm 0.0934\, Ps$

Activation Energy of Viscous Flow:

- $E = -6.727 \cdot 10^{-20} \pm 1.703 \times 10^{-21}\ J$
- $E = -0.4199 \pm 0.0106\ eV$

Summary

The experiment measured the viscosity of paraffin oil at various temperatures using a Höppler viscometer. Results confirmed that viscosity decreases with rising temperature, consistent with theoretical expectations. While the activation energy of viscous flow, calculated as $-0.4199\ \ eV$, falls within the acceptable range for similar substances, the viscosity values appear higher than typical theoretical values. Uncertainty calculations validated the reliability of the experimental setup, suggesting the possibility of systematic error in the measurements.

Measurement card

02.12.24 r.

Physics laboratories - Determining the temperature dependence of the viscosity coefficient of liquids with the Höppler viscometer

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No.	Temp., °C	ball fall time t, min,s 1.	2	3
1.	26	2.14,6	2.13	2.13,3
2.	30	1.44,9	1.43,9	31° 1.39,6
3.	35	1.23	35,5 1.21,1	1.18, 4
4.	40	1.05,5	1.02,5	1.01, 5
5.	45	0.51	0.49	0. 48, 9

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