Experimental Competition

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<u>Experimental problem 1</u>

<u>Using the interference method to measure the thermal expansion coefficient and temperature coefficient of refractive index of glass (10 points)</u>

(1) Instructions

Optical instruments are often used at high or low temperatures. When optical instruments are used at different temperatures, the thermal properties of the materials, of which the optical elements were made of, including thermal expansion and the variation of refractive index with temperature, will directly affect their optical properties. Two parameters, i.e. the linear thermal expansion coefficient β and the temperature coefficient of refractive index γ, are defined as $\beta = \frac{1}{L}\frac{dL}{dT}$ and $\gamma = \frac{dn}{dT}$ respectively to describe these properties, where L stands for the length of the material, T the temperature, and n the refractive index. The purpose of the present experiment is to measure β and γ of a given glass material.

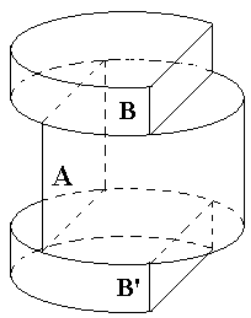

Figure 1

(2) Experimental apparatus, devices, and materials

<u>1. Sample</u>: The cylinder-like sample used in present experiment is made of uniform and isotropic glass, as shown in Fig. 1. Where A represents a glass cylinder with a segmental part parallel to its axis cut away, its top and bottom surface are approximately parallel to each other. B and B' are two circular plates made of the same glass material, from each of which a segmental part parallel to the axis was also cut away. The top and bottom surface of each glass plate are not parallel to each other. A, B, and B' are glued together as a whole, as shown in Fig. 1. The refractive index of the glue is as the same as that of the glass, and its thickness can be neglected.

2. Heater: The heater used in this experiment is schematically shown in Fig. 2. A knob on the right of the electric oven is used to adjust the temperature of the electric oven. A big aluminum cylinder was bored a co-axis pipe-like sample cavity in the middle of it,. The experimental sample can be put at the bottom of this cavity. Besides, there is a small aluminum cylinder, through which two tube-like holes of different radius were bored. The small hole allows light to pass through, while a probe of a thermometer can be inserted in the big hole. If you want to heat the sample, you should first slip the sample carefully into the cavity of the big aluminum cylinder before you heat it (in doing so, the big aluminum cylinder should be inclined somewhat to avoid cracking the sample). Next, put the small aluminum cylinder onto the sample already located in the cavity. Then, put the whole big aluminum cylinder including the sample and the small cylinder inside into the steel cup on the electric oven. (For heating, you should not put any water in the steel cup, and you shouldn't take away the steel cup but put the whole aluminum cylinder directly on the oven, either.)

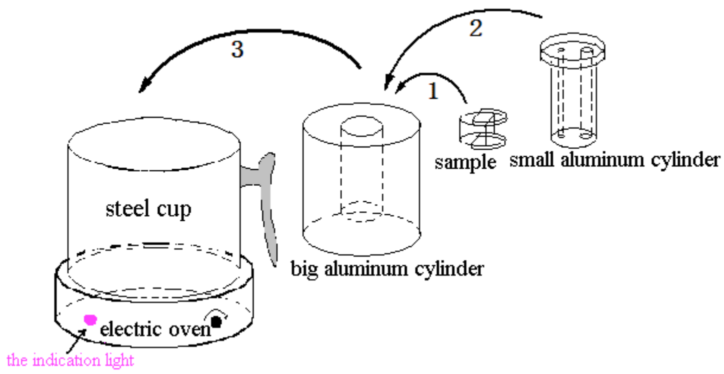

Figure 2

3. Light source holder. As shown in Fig. 3, a support consisting of a vertical post and a base trestle is designed to hold the laser light source. The post and the base trestle are fixed together at C and two tunable adjusting screws A and B are attached to the trestle. A He-Ne laser and its power supply are held at the upper part of the post, as shown in Fig.3. Just below the laser, a slant bracket is attached to the power supply, on which is placed an aluminum plate with a hole through it. A piece of graph paper is attached to the aluminum plate, which can be used as an observation screen.

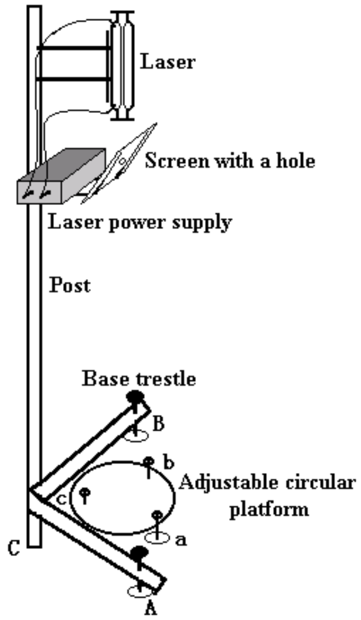

Figure 3

4. Sample platform: A circular platform with three adjusting screws *a*, *b*, and *c* is designed to hold the heating oven or the big aluminum cylinder including the sample and the small aluminum cylinder. The platform is placed on the experimental table, close to the base trestle, right below the laser light source, as shown in Fig 3.

5. A digital thermometer

6. A straight ruler

7. A basin (containing the cooling water)

8. A piece of towel

9. A piece of graph paper

10. A calculator

11. A pen and a pencil

【Attention】

a. Never look at the laser light source along the direction opposite to the incident direction of the light. Otherwise, the laser light might hurt your eyes.

b. Never touch the optical surface of the sample. Take the sample gently to avoid any damage.

(3) Experimental content

1. Answer Questions **(2.4 points)**

1.1 When a beam of white natural light coming from a lamp and passing through a piece of red transparent paper strikes on a thick glass slab of a thickness about 2 cm, the beams reflected from the top and bottom surfaces of the slab meet at the observation screen, resulting in a light spot on the screen without interference fringes, as shown in Fig.4 (a). However, when a laser beam strikes on the same glass slab, the reflected beams meet at the same observation screen, resulting in a light spot with interference fringes, as shown in Fig. 4(b). What is the reason accounting for these two different phenomena? (choose the correct one)

A. The laser beam is stronger than the red beam
B. The laser beam is more collimated than the red beam
C. The laser beam is more coherent than the red beam
D. The wavelength of the laser beam is shorter than that of the red beam

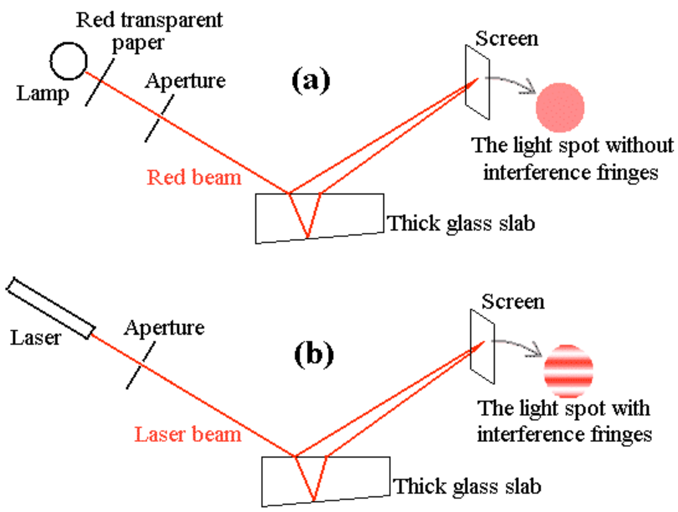

Fig.4

1.2 a As shown in Fig.5, if a laser light beam strikes approximately normally on the region *a*, *b*, and *c* of the sample respectively, how many main light spots of the reflection light will be observed (need not consider multiple reflections)? Will the profiles of these reflected optical spots be inevitably the same as that of the incident light?

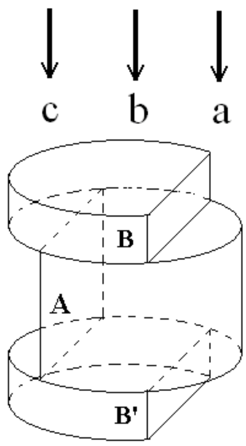

Fig. 5

1.2 b If the profile of some spots of the reflected light is different from that of the incident light? Please give a reason to account for.

2. <u>Experiment</u>: Measurement of β and γ of the glass **(7.6 points)**

With the wavelength of the laser light $\lambda = 632.8\text{nm}$, the height of the glass cylinder A $L = 10.12 \pm 0.05\text{mm}$, and the average refractive index of the glass corresponding to this given wavelength and the given temperature range of measurement $n = 1.515$, measure the thermal expansion coefficient β and the temperature coefficient of the refractive index γ for the glass sample over the temperature range from 40°C to 90°C.(Within this temperature range β and γ may be taken as constant.)

2.1 Design the Experiment, draw the experimental ray diagrams and derive the formulae relevant to the measurement. (3.2 points)

2.2 Carry out the experiment and record the measured data of the thermal expansion coefficient β and γ. (1.6 points)

2.3 Calculate β and γ of the given glass material and estimate their uncertainties. (2.6 points)

2.4 Write the final experimental results. (0.2 points)

【Attention】

1. When put the sample into the sample cavity of the big aluminum cylinder, in order to avoid cracking the sample, incline somewhat the big aluminum cylinder, and make the sample slip towards the bottom of the sample cavity carefully and

slowly.

2. During the process of experiment, the temperature can be increased continuously. In order to guarantee enough time you better to measure your data when the temperature is increasing. To heat the sample, the knob of the electric oven may be first turned to its maximum. When the temperature approaches to near 90℃ (around 85℃), turn the knob to the minimum immediately to stop heating. During heating, the indication light on the left of the oven might be off and then on again. This indicates that the oven is controlling the temperature itself automatically. Do not care about it.
3. After the sample in the cavity of the big aluminum cylinder is heated enough, its natural cooling down will be very slow. To get a rapid cooling, you may put the heated steel cup containing the big aluminum cylinder with the small aluminum cylinder inside into the water-filled basin. After a while of cooling（at least 5 minutes）, carefully use the towel to wrap the big aluminum cylinder and put it directly into the cooling water to speed up the cooling process. Be careful to avoid burning your hand. After cooling, use the towel to dry the big aluminum cylinder, and put it back to the steel cup, then you can heat it again. In order to avoid short circuit, never pour any water into the electric oven.
4. When you finished the experiment, turn off the electric oven immediately to avoid overheating.

Warning: Be careful in your experiments! If your sample or instrument is broken, you may have difficulties to continue your experiments, since we do not have enough backups!

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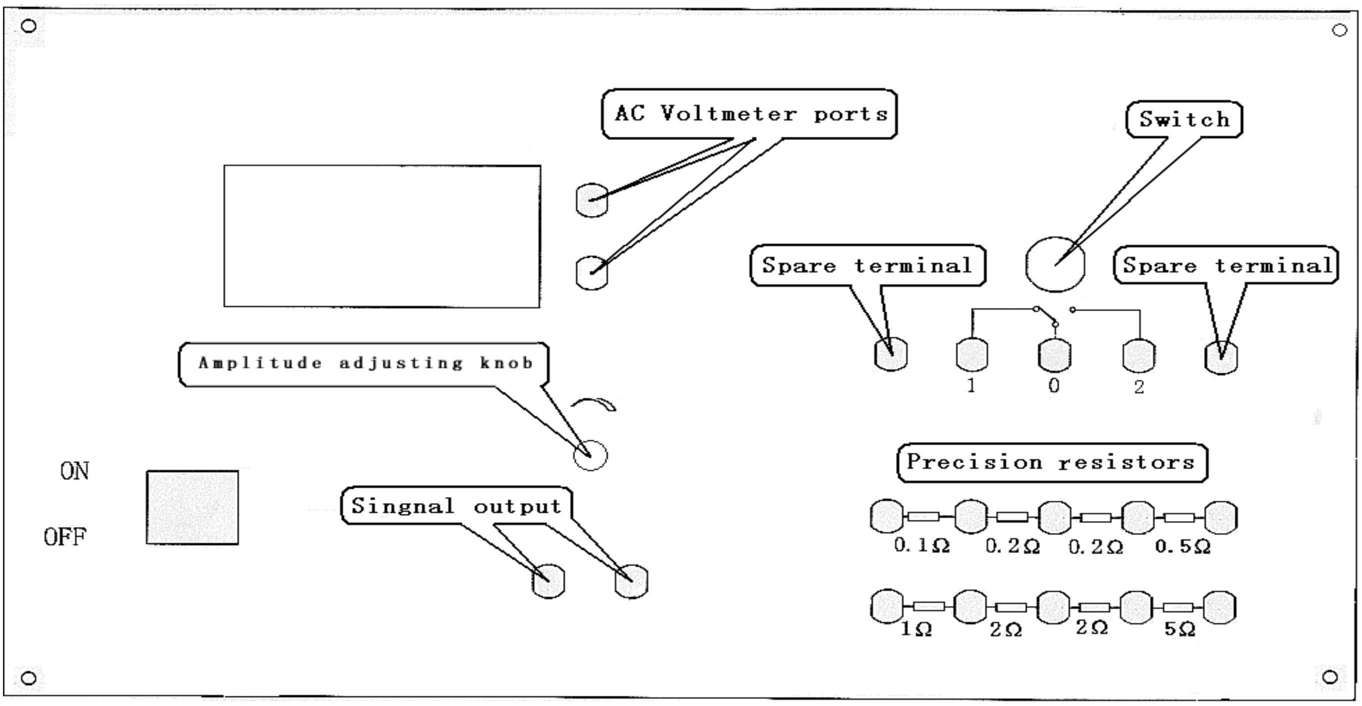
Panel Instruction



Note: The AC voltmeter black port is connected with two spare terminals

Experimental problem 2

Measurement of liquid electric conductivity（10 points）

1. Experimental instructions

In the apparatus of present experiment to measure the conductivity of liquid (i.e., water with salt), the sensor deals with *ac* signal without any contact potential involved to interfere with the desired experimental results. Meanwhile, since the sensor (detective winding）does not directly touch the liquid to be measured, no chemical reaction would happen during the experiments to damage any part of the apparatus. Therefore it can be used repeatedly for a long time.

As shown in Fig. 1, the sensor designed for measuring the conductivity of liquid consists of two circular loops with the same radius, made of soft-iron-based alloy. Each loop is wound with winding. The numbers of circles of the two windings are equal to each other. The two alloy loops are aligned along the same axis and connected closely as one airproof hollow cylinder, as shown in Fig. 2.

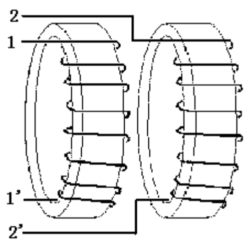


Fig. 1

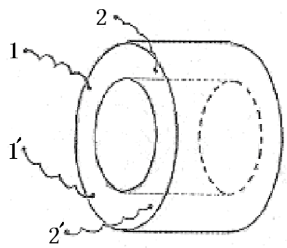


Fig. 2

The sensor is immersed in the liquid to be measured. Winding 11' is connected to *sine* signal generator of frequency about 2.5kHz. The amplitude of its output signal might drift somewhat. If the drift exceeds certain value, it should be adjusted in time to keep the output amplitude remain at certain value. Winding 22' is connected to *ac* voltmeter used to measure the induced signal voltage. With the measured magnitude of the signal voltage, the conductivity of the liquid can be calculated.

2. Experimental principles

The operation principle of the present experimental apparatus can be simply explained as follows. The *ac sine* current from the signal generator induces an *ac* magnetic field in loop 11'. In turn the magnetic field induces an *ac* current in the conducting liquid. Such induced current induces back a time-varying magnetic field in loop 22', which induces an electromotive force in the same loop 22', being the output signal of the sensor.

Neglecting the magnetic hysteresis effect, output voltage V_o is a monotonical function of input voltage V_i. When input voltage V_i and the conductivity σ of the liquid are respectively within certain range, a proportional relation holds between σ and the ratio of V_o/V_i:

$$\sigma = K\ (V_o/V_i)\ , \tag{1}$$

where K is the proportionality constant.

In the present apparatus, the liquid container can contain so much liquid to be measured that the resistance of the liquid outside the cylinder-shaped sensor is negligible. Therefore the output voltage V_o of the sensor depends mainly on the 'liquid within the hollow cylinder' (referred as "liquid cylinder" hereafter). Thus, it is possible to use the liquid cylinder to calculate the liquid conductivity. Resistance of the liquid cylinder is

$$R = \frac{1}{\sigma}\frac{L}{S}, \quad \sigma = \frac{1}{R}\frac{L}{S} \tag{2}$$

where L is the length of the liquid cylinder along its axis, and S is the area of its cross section. Combination of (1) and (2) leads to:

$$V_o/V_i = (\frac{1}{K}\frac{L}{S})\frac{1}{R} = B\frac{1}{R} \tag{3}$$

where $B = (\frac{1}{K}\frac{L}{S})$, or alternatively $K = \frac{1}{B}\frac{L}{S}$.

With Eq.(2) and (3) we obtain

$$\sigma = (\frac{1}{B}\frac{L}{S})V_o/V_i\ . \tag{4}$$

Equation (4) shows that, when using the present sensor to measure the liquid conductivity, σ is related to L (length of the hollow cylinder), S (area of its cross section), V_o/V_i, and B as well.

Remark: Essentially in the present experiment, in order to obtain the proportionality constant K and then B accurately, various kinds of liquid with known

σ should be required and prepared. Obviously this is not an easy task. Therefore, for the sake of both convenience and correctness, instead of the various liquids of known σ, we use externally connected standard resistors. The two ends of the standard resistor are connected to the two ends of a conducting thread passing through the hollow cylinder of the sensor to form a resistor circuit, as shown in Fig. 3.

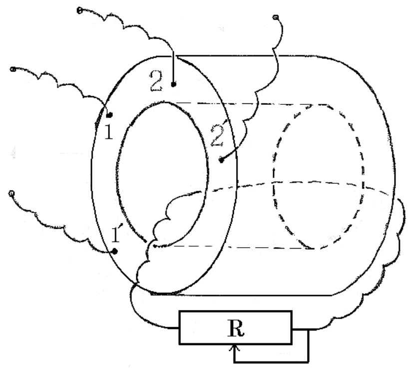


Fig. 3

3. Experimental content

1. Draw the experimental circuit diagram for scaling the sensor of the liquid conductivity (1.0 points) , and complete the connection of the circuit in order to measure both the input voltage V_i (<2.000V) and induced output voltage V_o according to the above circuit diagram (1.0 points).

2. According to the range of resistance of standard resistors: 0—9.9 Ω, measure V_o/V_i for various resistances. Record the data in the data Table designed by yourself. (2.0points)

   Control the amplitude of V_i at any moment to make sure that its effective value is within the range of [1.700V, 1.990V] and its variation should not be higher than 0.03V. You can also fix the input voltage at a single value within this range. (1.0 points)

3-1. Take V_o/V_i as ordinate and the reciprocal of resistance R of the standard resistor $1/R$ as abscissa. Draw the curve of V_o/V_i versus $1/R$. The number of measurement points should be greater than 20 within the whole output voltage range, and you are not required to add error (uncertainty) bars to the graph, but should estimate the uncertainties from the scatter points. (1.0 points)

3-2 It can be seen that at some region of less induced current the curve is linear. Graph this linear part and use the graphical method to obtain the slope *B* of the straight part of the curve and its relative uncertainty *u(B)* or *u*(*B*)/*B*. (1.5 points)

4. With the given axis length of the sensor *L*=(30.500±0.025) mm and diameter of the liquid cylinder *d*=(13.900±0.025)mm, calculate the value of K and *u(K)* or *u(K)/K*. (1.0 points)

5. Work out the conductivity of the liquid in the container and write the result. According to the uncertainties of *L*, *d*, and *B*, estimate the uncertainty of the conductivity. The measurement of the conductivity should be done for six times, during which the liquid should be stirred for each time. (1.5 points)

4. Instruments and materials

1. Sensor of liquid conductivity
   The sensor has four ports of connection terminals: two terminal ports are connected to winding 11' and two terminal ports are connected to the other winding 22'.
2. Container filled with the yet-to-be-determined liquid and stirring rod.
3. The instrument for measuring the liquid conductivity.
   On the instrument panel there are:
   - Signal generator:
     Two ports of connection terminals connected to the signal generator, the red one for signal output, and the black one for grounding. The amplitude of output signal can be adjusted by turning the knob.
   - *ac* digital voltmeter.
   - Inserting-type resistor box:
     On the panel, there are many ports of connection terminals, between every two adjacent ports, there is a resistor with relative resistance error of 0.001. Resistance of these resistors is 0.1,0.2, 0.5,1,2, and 5Ω respectively.
   - Switch 1×2（single-pole double throw）.
4. Some leads
5. Two pieces of graph paper (20cm×25cm), calculator, recording paper, ruler, and pen.