1. Experimental Objectives

1) Calibrate the silicon resistance strain sensor using weights, calculate the sensitivity, and learn how to calibrate a force sensor.
2) Observe the physical process and physical phenomena of liquid surface tension using pulling and breakaway method, and analyze and study the physical phenomena using basic physical concepts and laws to deepen the understanding of the physical laws.
3) Measure surface tension coefficients of water and other liquids.
4) Measure the relationship between liquid concentration and surface tension coefficient (such as surface tension coefficients of alcohol at different concentrations).

2. Precautions

1) Hanging ring should be clean. To clean the ring, use NaOH solution first followed by water, and then use hot blower for drying.
2) Hanging ring should be leveled. 1° deviation yields 0.5% error and 2° yields 1.6% error.
3) Preheat for 15 minutes for stable operation.
4) Turn the lifting screw with care, when adjusting the height of the container platform, to reduce fluctuations of liquid surface.
5) The apparatus should be operated under no wind environment or minor air disturbance to avoid the swinging of the ring.
6) If pure liquid is used in the experiment, impurities like dust and oil should be avoided in the process. Do not touch the liquid with bare fingers.
7) The force limit of the sensor is 10 g. Excessive pulling of the sensor could damage the sensor.
8. After experiment, clean and dry the hanging ring, and store it in a dry container.

3. Experimental Procedures

1) Turn on power and warm up for 15 minutes.
2) Clean glass container and hanging ring.
3) Pour liquid into the glass container, and mount the container onto the lifting stage. (Double sided tape may be used on the container bottom to secure the container).
4) Hang the small aluminum plate to the hook of the force sensor.
5) Calibrate the force sensor. Note: before adding weights, set the voltmeter readout to zero and place weights to the plate as gently as possible.
6) Take off the plate.
7) Measure the outer and inner diameters of the hanging ring, and then hang the ring to the hook of the force sensor.

8) Observe the buoyancy and tension phenomena of the ring exerted by the liquid. Turn the lifting screw in clockwise direction to lift the liquid surface. When the ring is fully immersed into the liquid, change the turning direction in counterclockwise to lower the liquid surface.
9) Observe the physical process and phenomena during the ring's immersing into liquid and lifting from liquid. Monitor voltmeter readouts carefully at the moment of pre- and post-breakaway, and record the corresponding U_1 and U_2 values.

4. Example for Data Recording and Processing

Note: Data below are for reference purpose only, not the criteria for apparatus performance.

Due to variations in water quality, the experimental data may vary. For this reason, tap water is not recommended; instead, pure Ethanol can be used.

1) Calibrate force sensor

Add weights to the force sensor, measure the corresponding voltage output, results are shown in Table 1.

Table 1 Calibration of force sensor

Weight (g)	0.500	1.000	1.500	2.000	2.500	3.000	3.500
Voltage (mV)	14.7	29.3	44.0	58.8	74.2	88.6	103.2

The sensitivity of the instrument is can be calculated by least-square fitting: B=3.013×10^3 mV/N with a fitting linear correlation coefficient r =0.9999. (Local gravitational constant g = 9.794 m/s^2).

2) Measure surface tension coefficients of water and other liquids

Measure the metal ring with a Vernier caliper: outer diameter D_1= 35.00 mm, inner diameter D_2 = 33.34 mm. Adjust height, record voltages U_1 and U_2 (pre- and post- breakaway), shown in Tables 2 - 4:

Table 2 Pure water (Temperature 25.0 ℃)

No	U_1 (mV)	U_2 (mV)	ΔU (mV)	f (×10^{-3} N)	α (×10^{-3} N/m)
1	45.5	0.1	45.4	15.05	70.1
2	45.4	0.2	45.2	14.99	69.8
3	62.5	17.2	45.3	15.02	70.0
4	82.1	36.7	45.4	15.05	70.1
5	82.3	36.7	45.6	15.12	70.4
6	87.0	42.2	44.8	15.88	69.3

The average surface tension coefficient is 70.0×10^{-3}N/m. The accepted value at T=25.0 ℃ is 71.97×10^{-3}N/m, yielding an experimental error of 2.7%.

Table 3 Ethanol (Temperature 25.2 ℃)

No	U_1 (mV)	U_2 (mV)	ΔU (mV)	f ($\times10^{-3}$ N)	α ($\times10^{-3}$ N/m)
1	26.7	12.4	14.3	4.76	22.2
2	30.8	16.4	14.4	4.76	22.2
3	31.4	16.8	14.6	4.86	22.6
4	31.1	16.7	14.4	4.76	22.2
5	28.5	14.0	14.5	4.82	22.4
6	29.2	14.7	14.5	4.82	22.4

The average surface tension coefficient is 22.3×10^{-3}N/m. The accepted value at T=25.2 ℃ is 21.95×10^{-3}N/m, yielding an experimental error of 1.4%.

Table 4 Glycerin (glycerol) (Temperature 24.3 ℃)

No	U_1 (mV)	U_2 (mV)	ΔU (mV)	f ($\times10^{-3}$ N)	α ($\times10^{-3}$ N/m)
1	59.6	21.7	37.9	12.58	58.6
2	67.3	29.9	37.4	12.42	57.8
3	65.0	27.6	37.4	12.42	57.8
4	63.3	25.4	37.9	12.58	58.6
5	61.0	23.3	37.7	12.50	58.2
6	61.8	25.5	36.3	12.03	56.1

The average surface tension coefficient is 57.9×10^{-3}N/m. The accepted value at T=24.3 ℃ is 59.40×10^{-3}N/m, yielding an experimental error of 2.5%.