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EXPERIMENNTAL ESTIMATION OF SURFACE TENSION BY LIGHT SCATTERING UPON SPHEROIDAL OSCILLATIONS OF A LEVITATING ULTRASONIC LIQUID DROP

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A possibility to estimate surface tension of a liquid drop by light scattering at a fixed angle is shown. Resonant nature of light scattering upon spheroidal oscillations of a drop is used.

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Study of optical and physical properties of particles suspended in a certain medium is of interest for various fields of science [1-4]. Search and development of new methods for determining such an significant characteristic of liquid drops as surface tension is undoubtedly an important objective.

The present work offers an experimental way of determining surface tension of a liquid drop by light scattering at a fixed angle.

An acoustic levitation was used to exclude the effect of a suspension string or substrate upon the estimated value of a drop's surface tension s [5, 8, 9]. It allows to "suspend" a drop in a fixed point along the axis of a cylindrical acoustic resonator by compensating the drop's gravity with a radiation pressure of a standing ultrasonic wave. Stable levitation of the drop allows to use the effect of excitation of forced spheroidal oscillations of the drop's shape [6-9] to increase sensitivity of measurements of light intensity I_s, scattered at a fixed angle close to normal with to the incident light beam. In this case I_s is recorded at an proper frequency of spheroidal oscillations of the drop f_2 Surface tension of the drop's substance at an interface with water, when the drop is experiencing spheroidal oscillations, is determined from:

$$\sigma = \frac{\pi^2}{6}(2\rho_e \div 3\rho_i)R^3 f_2^2 \qquad (1)$$

where ρ_e, ρ_i — are densities of the environment substance (water in this case) and the drop, respectively, R is a drop radius . When ρ_e, ρ_i — are known (from table data) and R has been measured for example with an optical microscope, f_2 can be determined by calculating the surface tension of the studied liquid σ.

A diagram of the experimental unit is shown in Fig.1. Optical system 1 is designed to form a parallel linear-polarized beam of laser radiation of sufficient cross section. Radiation source is a He-Ne laser with emission wavelength λ =0.63mm and output Po=1MW. Central part of the unit is a system of particle levitation and their shape oscillation excitation. It consists of an acoustic resonator 4, particle levitation system 8 and system 9 for particle shape oscillation excitation. The acoustic resonator is made of transparent optical glass in the form of a cylinder. The resonator is filled to an estimated height with fresh double-distilled water put through a system microparticle filtering. There is a cover on the top which is also an acoustic reflector, with an opening in the centre for the input of the studied particles.

Levitation system is designed to excite in the resonator an acoustic field of a configuration and power sufficient to keep an examined particle in a given point along the longitudinal axis of the resonator in a lasting and highly stable manner. The levitation system contains: a master oscillator of low-frequency signals GZ-51/1, a power amplifier, a matching reactive two-port and a ring piezoelectric radiator.

The principle of operation of the suspension system is the following. A change of frequency of the master oscillator excites one of the working modes of the piezoelectric radiator and as a result a definite type of acoustic oscillations with a specified field distribution in the whole space is set up in the resonator. For a glass resonator with an inside diameter d=27mm and a water column h=190mm at sound velocity v=1500m/s the working frequency of mode excitation(r, φ, z)=(1,0,16) equals $f_{1,0,16}$ =92,63 kHz. Length of the standing wave along z co– ordinate (resonator axis) is in this case Λ =23.8 mm.

Experimental study of distribution of the field of the standing wave of mode (1, 0, 16) in radial direction and in the longitudinal axis proved the accuracy of theoretical calculations.

Thus, the resonator produces an axis-symmetrical mode with a given distribution of the field in longitudinal and cross sections, securing a studied drop in a definite point along the axis of the resonator.

The system of excitation of particle shape oscillations is designed to form an acoustic field with a configuration, frequency and amplitude enabling to obtain forced resonance oscillations of the shape of a suspended drop at a frequency of natural oscillations of one of the modes with [9].

After reaching a stable levitation of the studied drop, amplitude of the modulating signal must be raised to a value, which provides optimum oscillation of the drop shape. Then maximum Q-factor of spheroidal oscillations of the drop must be reached by adjusting frequency f_2.

Optical TV system 10 for particle imaging is designed for real-time observation of oscillations of the drop shape and for estimation of sizes of studied particles. The system is based on a small-size TV unit MTU-1 which comprises an "Electronica L-50" TV-camera and video-display. The optical section of the system includes an "OI-19" illuminant, "MIR-2" reading microscope with adjustable magnification from 19x to 33x (measuring range 0.015 - 6 mm) and vidicon of the TV camera. Images of the drop on the photocathode of the vidicon of the camera are produced by a direct-shadow method. Extension rings for the camera lens enable to have images of particles down to 100 mcm.

Photoelectric system 11 is designed for recording the light scattered by particle. Optical part consists of a lens, slit diaphragm, interference filter for

λ = 0.63 m (halfwidth of the transmission band $\Delta\lambda$ = 50 A) and photocathode FEU-106 which is used as a converter of optical signals to electrical.

Modulation is applied to laser radiation amplitude using a mechanical chopper when the suspended particle sizes are controlled without excitation of shape oscillation. If there is excitation of shape oscillation the signal is amplitude modulated with frequency f_2. In both cases the signal parameters are determined with an electronic millivoltmeter V3-43 and oscillograph C1-73. A variable signal after conversion into d.c. voltage may be registered by recorder LKSZ-003.

System of diagnostics of acoustic field distribution in resonator 12 consists of a specially designed small-size probe with a piezoceramic microtransducer as a sensing element. To provide transducer movement along the axis of the resonator and on its radius the probe is fixed to a substage ST-12 which guarantees movement along both coordinates with an accuracy of 0.1 mm.

Benzene drops (C_6H_6)with R from ~500 to ~2000 mcm were studied experimentally. Calculation of the average surface tension for a number of studied Benzene drops within the given range of sizes and according to expression (1) gave the following value: σ_{exp} = 34.10 din/cm. With an account of an accidental error in measurements, the surface tension of a spherical drop of Benzene at the water interface (see the Table below) is:

$$\sigma_{exp\ p} = (34 \pm 2) \text{ din/cm.}$$

TABLE

Drop radius R, µm	765.00	962.00	1013.00	1136.00	1425.00	1733.00	1752.00
f_2, Hz	96.00	73.00	65.50	52.30	41.00	29.80	29.00
Q_2, exp.	10.00	9.70	10.00	12.00	10.00	13.00	13.30
σ_{exp}, din/cm	31.23	35.91	33.97	30.51	37.08	35.11	34.87

It is clear that the relative error in measurements does not excecde 6 %. The obtained value σ_{exp} is slightly less than the Table value for Benzene surface tension at the water interface: σ_{tabl} = 34.2 din/cm (at t = 27 °C) [10]. However, relative difference between σ_{exp} and σ_{tabl} is less than 1 %, i.e. it is within an experimental error.

Fig.2 shows an experimental resonance curve of spheroidal oscillations of a Benzene drop with $R = 1752$ mcm, illustrating possibilities of a high-accuracy estimation of surface tension of a liquid drop by a described method. The following calculated data were obtained for that drop: $f_2 \cong 29Hz$, $Q_2 \cong 15$[9]. Experimental Q-factor of spheroidal oscillations of a drop was determined from:

$$Q_2 = \frac{f_2}{\Delta f 0.7} \tag{2}$$

where $\Delta f_{0.7}$— is the curve width at level 0.7 from a maximum value of amplitude U of the oscillations. Calculation by expression(2) gives: $\dot{Q}_2 \cong 13$, i.e., there is good correspondence between experimental and theoretical data.

The study shows that the method considered is promising and requires further development.

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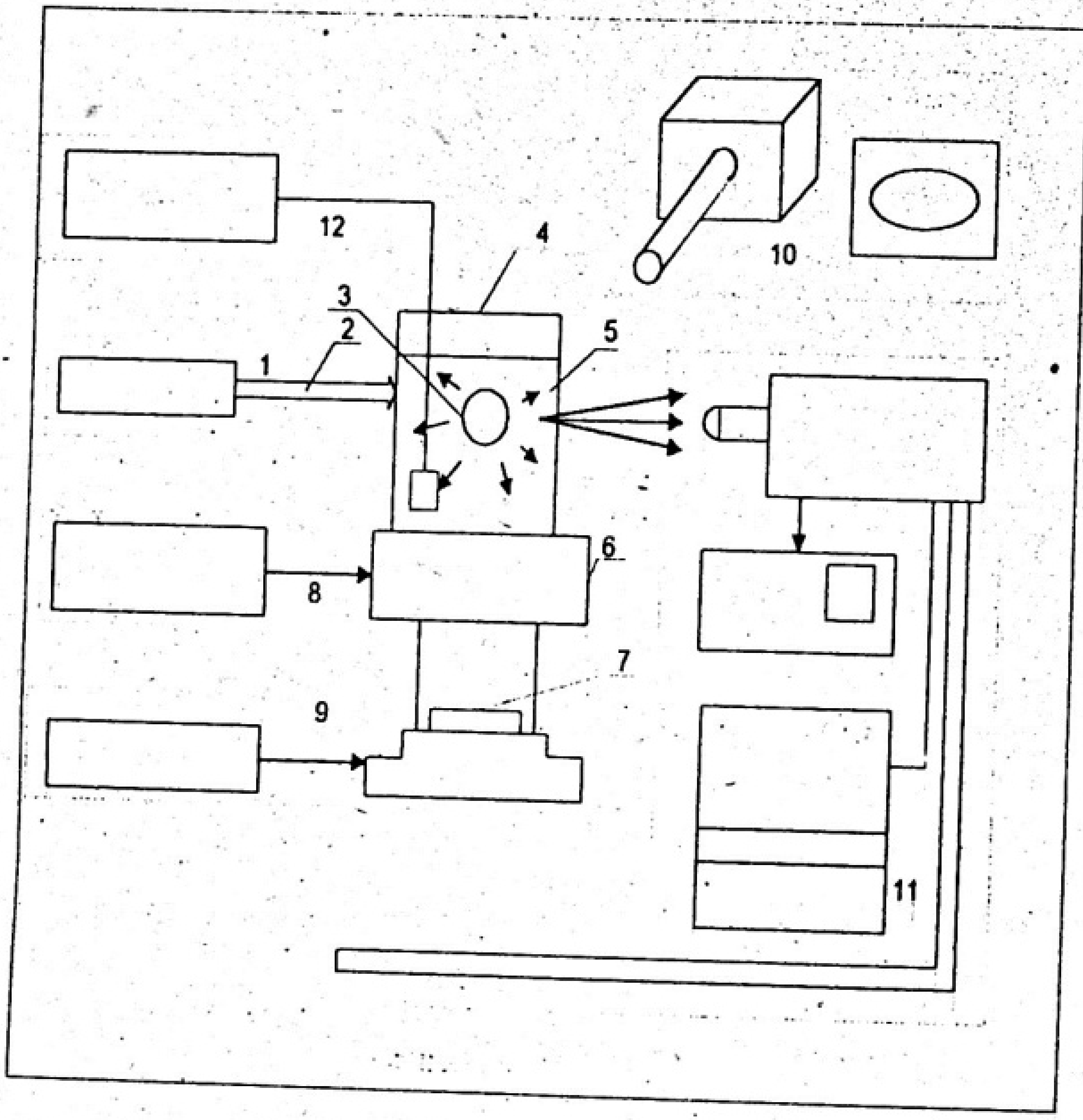

Fig.1 Block-diagram of experimental unit:
1 - optical system of light beam formation for particle sounding; 2 - sounding light beam; 3 - studied particle; 4 - acoustic resonator; 5 - liquid to fill up resonator; 6 - piezoelectric radiator of levitator; 7 - piezoelectric radiator exciting oscillations of particle shape; 8 - particle levitation system; 9 - system of excitation of oscillations of particle shape; 10 - optical TV system of particle imaging; 11 - photoelectrical system for recording particle scattered light; 12 - system of diagnostics of acoustic field distribution in a levitator's resonator

24	25	26	27	27.5	28	28.3	29	29.7	30	30.5	31	31.2	31.8
0.05	0.06	0.08	0.18	0.4	0.61	0.93	1.1	0.98	0.88	0.66	0.3	0.25	0.16

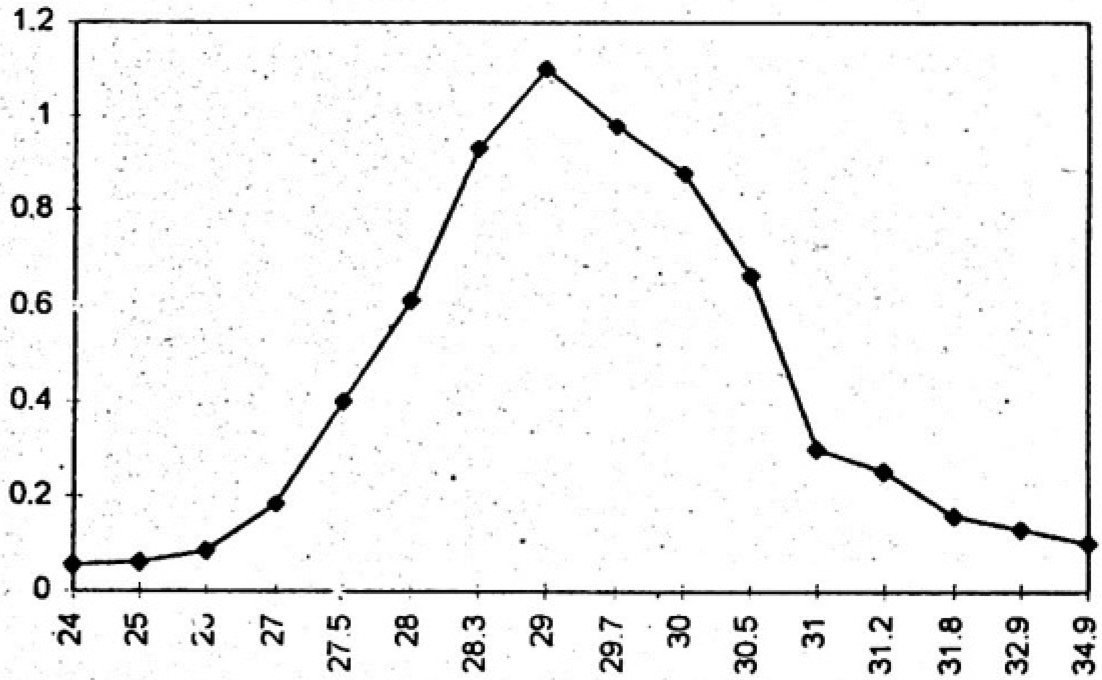

Fig.2. Experimental resonant curve of spheroidal oscillations of a benzene drop of radius R = 1752 mm levitated in water

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