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Methodological Notes

NEW DEMONSTRATIONS IN PHYSICS

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IN this article a description is given of several demonstrations shown at a public evening organized by the Physics Faculty of the V. I. Lenin Moscow State Pedagogical Institute on April 21, 1964.

1. PRINCIPLES OF IMAGE FORMATION IN A TELEVISION SET

A television image on the screen of a cathode ray tube is formed by means of a sequential reproduction of the brightness of all the elements (points) of the picture being transmitted.

This reproduction is carried out by an electron beam which traverses the screen in horizontal lines from right to left and from the top downwards, forming the television pattern. The image is obtained as a result of the variation of the brightness of the beam in the course of its passage along the lines corresponding to the brightness of the picture being transmitted.

The demonstration being described was proposed by docent V. S. Étkin and enables one by using easily available laboratory equipment to demonstrate the principle of obtaining a television pattern on the screen of a cathode ray oscillograph and to demonstrate the variation of the brightness of the beam in the course of its passage along the lines and the frames. A block diagram of the demonstration is given in Fig. 1.

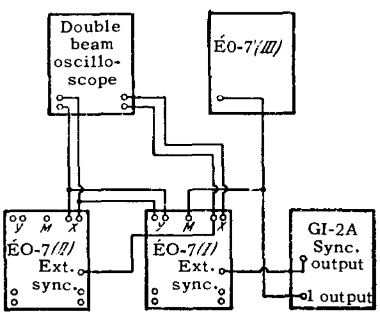

FIG. 1

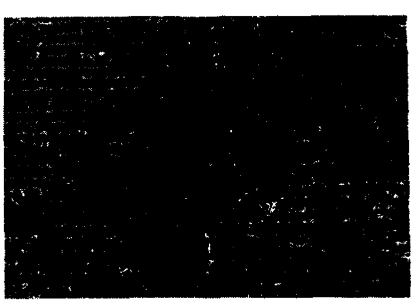

FIG. 2

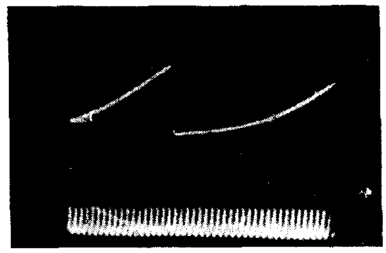

FIG. 3

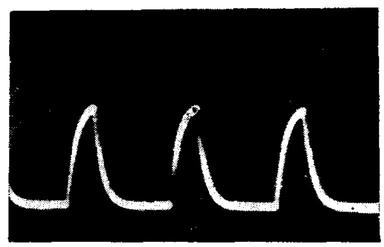

FIG. 4

For the demonstration the following equipment was used:

1. Three cathode ray oscillographs (ÉO-7).
2. Double beam oscillograph.
3. Pulse generator (GI-2A).

The appearance of the television pattern is observed on the ÉO-7 (I) screen (Fig. 2). The horizontal motion of the cathode ray beam is produced by the generator of the time base voltage of the same oscillograph. The voltage providing the vertical displacement is supplied by the sawtooth voltage from the ÉO-7 (II) time-base voltage generator, which is obtained from its X plates and applied to the Y plates of ÉO-7 (I).

The time base frequency of ÉO-7 (I) corresponds to the frequency of tracing out the lines of the television pattern, while the time base frequency of ÉO-7 (II) corresponds to the frame frequency of the television pattern. In order to synchronize these voltages the X-plates of ÉO-7 (I) are connected to the "ext. synchronization" terminals of ÉO-7 (II). The ratio of the periods of the frame and line voltages is made to be of the order of 20–30. For a visual comparison of the periods of these two voltages the voltages from the X-plates of ÉO-7 (I) and ÉO-7 (II) are applied to the inputs of the double beam oscillograph (Fig. 3). In order to observe the variation in the intensity of the beam the

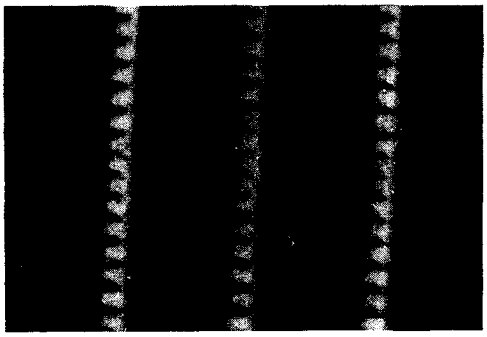

FIG. 5

voltage from output 1 of the pulse generator GI-2A is applied to the terminal "brightness" of ÉO-7(I). The pulses coming from this generator are observed on the screen of ÉO-7(III) (Fig. 4); they vary the brightness of the beam as it traverses a line. If the periods of the pulses and of the line traversal are integral multiples of each other then the darkening of the beam begins at a definite point in the cycle of the horizontal line traversal, and one observes on the screen a definite displace of vertical dark bands (Fig. 5).

2. OVERVOLTAGES ARISING WHEN A CAPACITANCE IS CHARGED BY MEANS OF A CIRCUIT CONTAINING AN INDUCTANCE

The use of an oscillograph of type S1-4 which contains in its input a d.c. amplifier and which has a long-persistence screen enables one to observe the process of the charge of a condenser from a d.c. voltage source and its discharge through an inductance and a resistance. The circuit is shown in Fig. 6.

In the position of the switch 1-2 the capacitor is charged from the d.c. voltage source. Because of the inertial properties of the inductance and of the existence of a phase shift between the voltage on the capacitor and the current in the circuit the voltage across the capacitor oscillates about a value equal to the voltage of the constant source. The oscillations are damped. The magnitude of the damping depends on the resistance. The frequency of the oscillations depends on the capacitance. Figure 7a—c shows the oscillations of the voltage for different values of resistance and capacitance (the inductance is not varied in the course of the experiment).

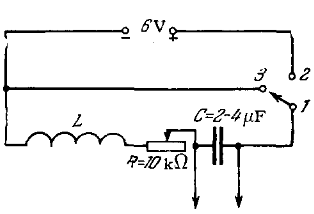

FIG. 6

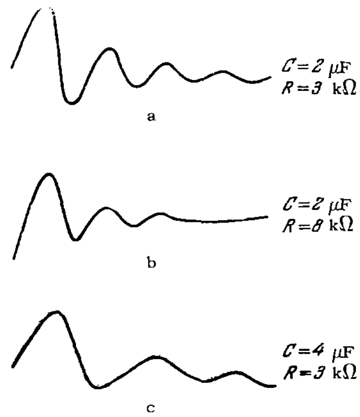

FIG. 7

In the position of the switch 1-3 the capacitor discharges in a manner similar to that in which charging occurs (Fig. 8).

In the absence of an inductance both processes occur without oscillations (Fig. 9). This demonstration can be usefully accompanied by a demonstration of a mechanical analogy. If a loaded spring is acted upon by a constant force then the end of the spring will not take on its new position of equilibrium immediately, but because of the inertial properties of the spring it will oscillate about the new position of equilibrium, and this is the mechanical analogy of the charging of a capacitor.

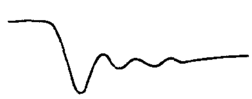

FIG. 8

FIG. 9

3. ZONE PLATE FOR ACOUSTIC AND ELECTROMAGNETIC WAVES

In the well-known "Demonstration Experiment with a Zone Plate" [UFN **82**, 166 (1964), Soviet Phys. Uspekhi **7**, 54 (1964)] the indicator of the effect of the zone plate is a cathode ray oscillograph which records the increase in the amplitude of the sound oscillations when the front of the acoustic wave passes through the zone plate.

From a methodological point of view it is of greater interest to observe the effect of the action of the zone plate in the case of acoustic waves directly by ear noting the variation in the loudness of the sound as a result of the action of the zone plate. In order to do this the arrangement shown in Fig. 10 is proposed.

The zone plate is operated in sound waves of 3 cm wavelength (f = 10 kcs). Oscillations of this frequency

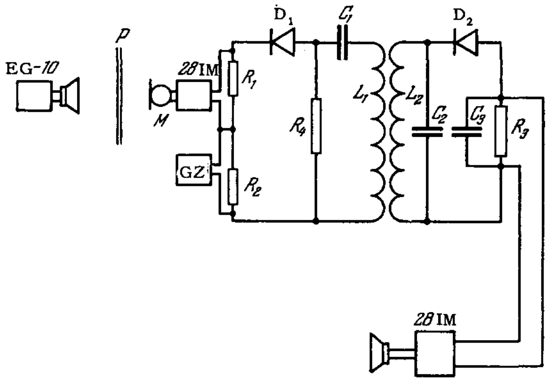

FIG. 10

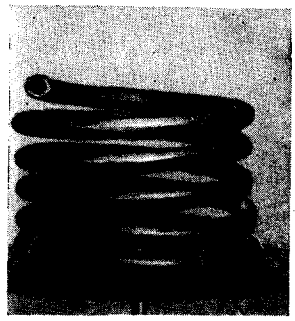

FIG. 11

are taken from the microphone M, are amplified and modulated by oscillations of lower frequency (f = 600—800 cps), which are applied to the modulating circuit from the audio frequency oscillator GZ-1.

The amplitude-modulated signal is taken from the L_2C_2 circuit tuned to the carrier frequency of 10 kcs, and is then detected by the detector D_2. A low frequency signal appears in the R_3C_3 circuit, and is then amplified and applied to the dynamic speaker.

The power of the reproduced sound oscillations of the carrier frequency is very low, since the operating range of the dynamic speaker extends only up to 6 kcs. Therefore the sound output of the dynamic speaker does not interfere with the observations. The introduction of the zone plate leads to an increase in the amplitude of the carrier frequency, and this, in turn, leads to an increase in the amplitude of the detected low frequency which is reproduced by the dynamic speaker at the output of the circuit. Since this frequency falls within the working range of the dynamic speaker the power of the sound oscillations of this frequency is sufficiently great, and this enables one to audibly observe the effect.

The same zone plate can be utilized for working with electromagnetic waves of 3 cm wavelength ($f = 10^{10}$ cps), with an oscillograph being used for the display.

4. FREE AXES OF AN ASYMMETRIC BODY

Stable rotation of an asymmetric solid body about a free axis with respect to which the moment of inertia of the given body has the greatest value can be observed by means of the following experiment which represents an extension of the well-known experiment with symmetric bodies.

A brass rod is suspended by a long thin thread from the axis of a vertically situated electric motor in such a way that the continuation of the thread lies along the axis of the rod.

The initial rotation about this axis is not stable in the case of a rod, and, therefore, as it rotates the rod gradually takes on a position in the horizontal plane rotating about a free axis with respect to which its moment of inertia has the greatest value.

By varying the distribution of the mass along the axis of the rod (a massive washer is attached to one end of the rod) one observes the change in the position of the free axis.

5. A MODEL OF THE TOLMAN EXPERIMENT

A metal or a glass coil (Fig. 11) open at one end and filled with colored water is placed on a centrifugal force machine with a vertical axis; it represents a Tolman coil. The machine is set into slow rotation (1—2 r.p.s.) by hand and is then stopped suddenly. The stream of liquid splashing out of the coil represents the motion of conduction electrons.

6. A MODEL OF THE STERN-GERLACH EXPERIMENT

The lower end of a glass tube, in which small compass needles of 35 mm length (from a set of equipment used for demonstrations of magnetism) are made to slide down, is placed between the poles of an electromagnet. On passing through the magnetic field the compass needles fall on a horizontal plane covered by cheesecloth or cotton wool which enables one to fix the points at which the needles fall. Three variants of the experiment are demonstrated:

a) If the diameter of the tube is greater than the length of the needles, and the magnetic poles are sufficiently broad so that the field can be regarded as uniform, the needles assume random distribution of positions below the tube opening.

b) If the field is not homogeneous (to achieve this one of the poles is shaped like a small cone), then in addition to the needles which fall almost opposite the opening one observes a more or less symmetric scatter in both directions from the tube axis.

c) But if one takes a tube of sufficiently small diameter so that the needles in sliding down it are oriented along its axis (this is used to represent spin orientation), then on passing through the inhomogeneous field the needles fall into two sharply defined groups on both

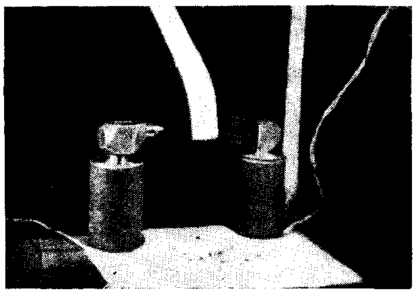

FIG. 12

sides with respect to the tube opening (in analogy with atoms in a Stern-Gerlach experiment).

Naturally, in sliding down the tube some of the needles must move with their north pole forward, and some with their south pole forward. The experiment is demonstrated sufficiently clearly by using 15–20 compass needles. The demonstration requires a certain relatively uncomplicated adjustment. An approximate arrangement of the details of the experiment is shown in Fig. 12.

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EXPERIMENTS WITH A SUPERHEATED LIQUID

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THE usually observed boiling of a liquid is associated with the presence in the system of artificial nuclei for vapor formation. If these nuclei are removed and care is taken to ensure good wetting of the walls of the container by the liquid the latter can be appreciably superheated. In textbooks the question of the attainable degrees of superheating is not discussed, and the very fact of the possibility of a prolonged existence of highly superheated liquids is poorly known. It would be useful to introduce into practical instruction in physics appropriate laboratory experiments.

A liquid in the form of small droplets can be easily superheated to tens of degrees above its normal boiling temperature if one uses a suitable liquid surrounding medium. For saturated hydrocarbons of the methane series sulphuric acid can serve as such a medium. Figure 1 shows a schematic diagram of the apparatus which is used in the Physico-Technical Faculty of the Ural Polytechnical Institute both for research purposes and for student laboratory exercises. The glass tube 4 is filled with sulphuric acid. In flask 2 by means of a magnetic rotating stirrer 1 emulsification in sulphuric acid is made to occur for pentane, hexane or some other liquid under investigation. Droplets of diameter 0.1–0.5 mm reach the tube 4 through the connecting capillary 3 and float upwards in it. A heater is wound on the aluminum block 7. In the sulphuric acid a vertical temperature gradient is set up which gradually decreases with height and in the neighborhood of the window amounts to ~ 0.1 deg/mm. The droplets floating upward are superheated, and having reached a definite temperature become unstable with respect to the formation within them of incipient vapor bubbles and then evaporate explosively. The characteristic crackling produced by this can be clearly heard throughout

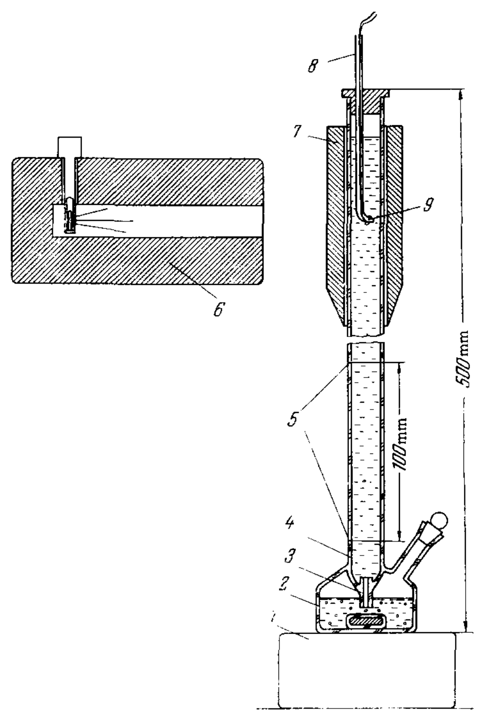

FIG. 1. Schematic diagram of apparatus for the determination of lifetime of droplets of superheated liquid.

the room. By introducing a thermocouple at the position of the explosion one can with good accuracy determine the corresponding temperature of the medium, and from that the temperature of the droplets. The correction associated with the failure of the rising droplet to attain the temperature of the surrounding medium can be reduced to a tenth of a degree or less[1].

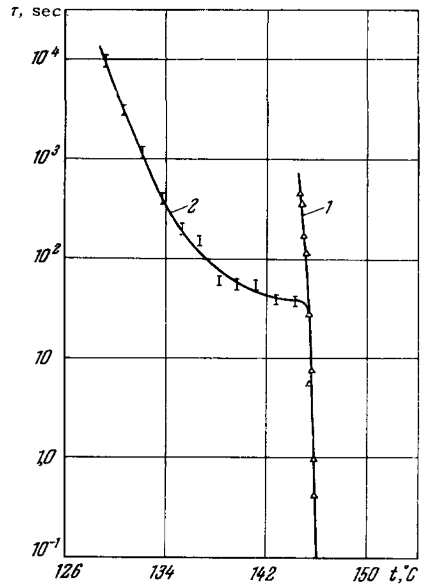

FIG. 2. Dependence of the mean life of droplets of superheated n-pentane on the temperature at atmospheric pressure: 1 – under natural conditions; 2 – under the action of γ-radiation; normal boiling temperature of n-pentane is 36.1°C.

More detailed information on the attainable superheating of a liquid can be obtained by bringing the droplets to rest at a given temperature. In order to do this one uses the glass tube 8 with a sealed off lower end. The end is slightly flattened, plane polished and has a small depression (~ 0.2 mm). Within the tube and in contact with its lower end there is inserted a measuring copper-constantan thermocouple with wire of diameter 0.1 mm. The horizontal "snout" 9 is displaced with respect to the axis of the tube. This enables one by rotating the tube in the teflon stopper either to place the "snout" in the path of the droplet, or to remove it to one side. Observations have shown that the droplets explode at the same temperature whether held against the snout or rising freely. Possibly the droplet is not in contact with the glass but is separated from it by a thin film of acid. A small bubble of vapor remains on the "snout" after the explosion; it can be easily shaken off by rotating the tube sharply, and this turns out to be sufficient to prepare the "snout" for the next experiment. It is more convenient to let the droplets come in short bursts, and to switch the stirrer on for 2–3 sec. The size of the droplet is determined from the time of rise between two marks 5 on the lower unheated portion of the tube. The distance between the marks is 100 mm.

The proposed method is simple and gives reproducible results in agreement with the theory of spontaneous boiling of a pure liquid[2-5]. Observation of the lifetime of superheated droplets shows a sharp temperature limit on the attainable degree of superheating. Curve 1 in Fig. 2 shows on a semilogarithmic scale the temperature dependence of the mean life τ of droplets of n-pentane with superheating exceeding 100°. The normal boiling temperature of n-pentane is 36.1°C. The data for the different droplets have been reduced to the same mass of 7×10^{-6} g which corresponds to a diameter of 0.28 mm at 20°C. For this mass of liquid according to the Dering-Volmer formula[2] (cf., also [6]) the value of $\tau = 1$ sec is reached at a temperature of 147°C.

The apparatus can also be used to determine the lifetime of droplets under the action of γ-radiation in the sensitive zone of the superheated liquid. Experiments of this kind are analogous to an investigation of the density of tracks of ionizing particles in bubble chambers. In both cases the determining factor is the probability of a triggered boiling of micro-volumes of superheated liquid. A source of Co^{60} is contained in the lead gun 6 placed on a rotating platform. The distance from the source to the apparatus is so chosen that the mean lifetime of droplets within a small temperature range would be of the order of tens of seconds. It is then convenient to record both short and long lifetimes. The use of a source of low activity (0.3 mg-equiv Ra) makes it safe to carry out the experiments.

At a given temperature the lifetimes are distributed in accordance with the Poisson law with a dispersion equal to the mean lifetime τ. From this follows the necessity of observing a large number of drops. Figure 2 shows the temperature dependence of τ for droplets of superheated n-pentane under the action of γ-radiation (curve 2). The data refer to a mass of 7×10^{-6} g and are obtained from experiments with 60–160 drops at each temperature. From the graph we can see the arbitrariness of the concept of a lower boundary to the region of sensitivity to radiation of superheated liquid. As the temperature is lowered from 144 to 134°C the mean lifetime of a droplet increases from 36 to 400 sec. With respect to bubble chambers this means a decrease in the density of the track by an order of magnitude with other conditions being the same.

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