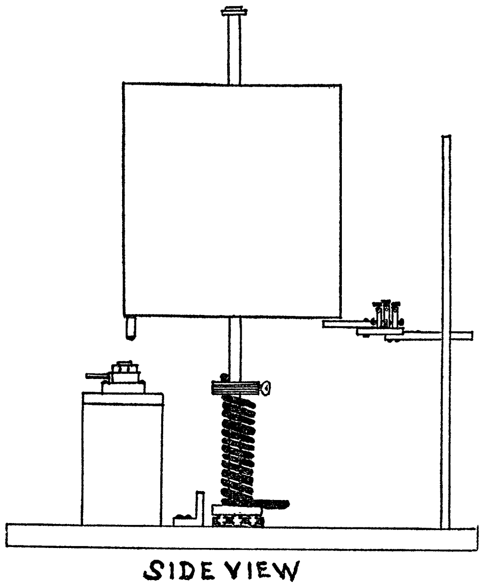
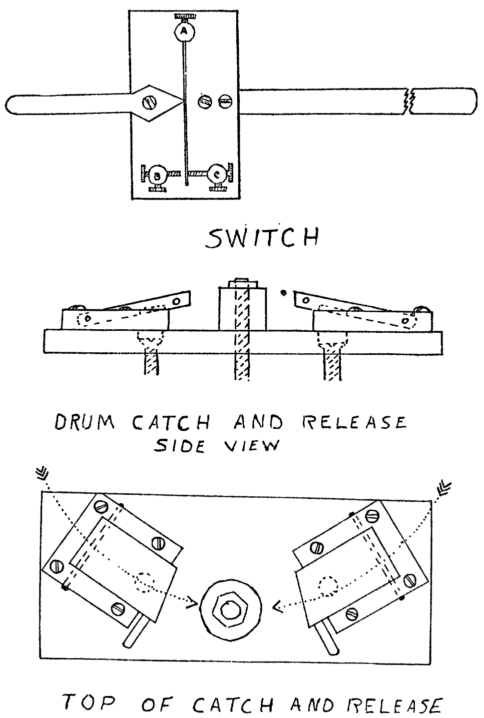


FIG. 1

makes the upper end of the spring fast to the hollow drum support and allows for spring tension adjustments.

The switch assembly is self-explanatory, and either spring brass or steel may be used for the vane. Contact points may be platinized if desired.

The most difficult part of the assembly to make is the drum catch and release. Figs. 3 and 4 give a top and side view of this in proportions. One fourth inch brass plate is used to cut out the U-shaped retainers for the catches. These catches are normally held up by spiral brass springs placed over the set in bolt heads, the shanks of which run to the base plate. Quarter inch brass plate is used to mount the catches and central bumper post on, the entire catch and release assembly is mounted on a wooden block which is firmly attached to the base plate by the three bolts. The center bolt is fitted with a rubber stopper to reduce noise and prevent backlash.



FIGS. 2, 3 and 4

The catch and trip pin on the drum is a brass machine screw, this is covered by fiber tubing, except at the wearing edge. The dotted arrow in Fig. 3 shows the path of the trip pin. By proper placing of the switches this trip pin will cause either make or break stimuli to occur. Since the switches function either right side up or inverted stimuli may be placed as close together as wanted or even be made simultaneous by placing one switch over the other.

In use the spring tension is adjusted to give a drum speed of approximately one centimeter per hundredth of a second. The drum pin is held by the catch and release is obtained by depression of the small pin projecting from the catch. If the base plate is not heavy enough to prevent jump of the assembly in use, a small quilt frame clamp such as found in dime stores may be used to fix the assembly to a desk top. Set screws must be employed to firmly fix the drum to its hollow support rod. All kymograph drums do not have these, but they are easily attached.

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MULTIPLE LABORATORY INCUBATOR FOR THE BIOLOGICAL STUDY OF CHICK EMBRYO

IN former publications in this journal,[1] and elsewhere,[2,3] I have emphasized that the accurate control of the most important physical factors, such as temperature, humidity and composition of air, is absolutely indispensable in the experimental incubation of hen's eggs. The importance of such control in all physiological and physicochemical studies of the embryo is obvious when daily observations have to be made on a small number of various individuals.

The laboratory incubator previously described[1,2,3] had already given excellent service by its accuracy in the control of the various physical factors and by its adaptability to a wide range of experimentation. With this incubator we were enabled to obtain very

[1] A. L. Romanoff, SCIENCE, 69: 197–198, 1929.

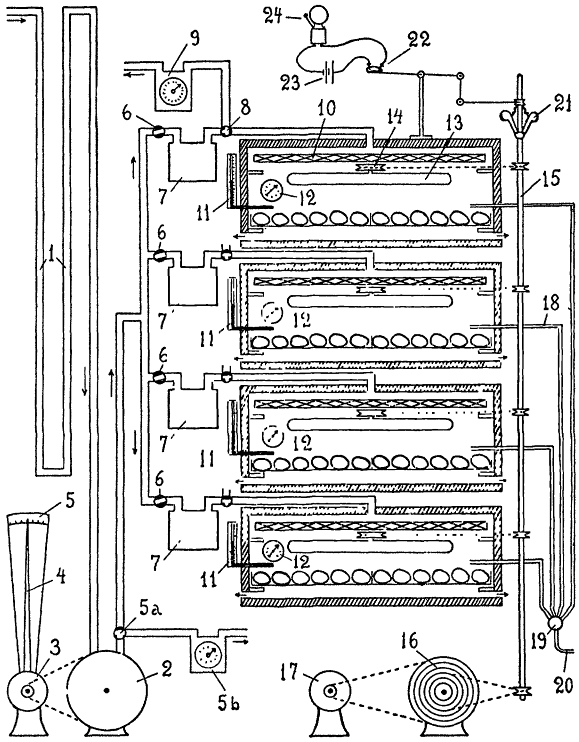
[2] A. L. Romanoff, *Cornell Univ. Agr. Expt. Sta. Memoir*, 132: 1–27, 1930.

[3] A. L. Romanoff, *Jour. Morph. and Physiol.*, 50: 517–525, 1930.

uniform and conclusive data on some phases of the embryonic growth,[4] metabolism and mortality, and also on the physicochemical changes in the egg contents under standardized,[5,6] or "normal" and adverse conditions of incubation: humidity,[2,7] composition of air,[3,8] and temperature.[9]

However, our experience showed that the above-mentioned incubator, being of a single-compartment only, is not efficient enough. Only a few experiments can be carried on during the natural hatching time, which is limited to about six months, that is, approximately from December to July. Secondly, when the results of several experiments are to be used for comparison, this incubator does not eliminate seasonal variation in the hatching quality of eggs; but it is a well-known fact that the average hatching of eggs varies throughout the season.

Therefore, in order to eliminate the influence of the season on the hatching quality of eggs and also to increase the efficiency of experimental work, we soon saw the need of a multiple, or of a several-compartment laboratory incubator, to carry on several experiments simultaneously. A commercial sectional incubator (vertical type, four compartments) was completely remodeled and all necessary special equipment was installed,[10] as shown on the accompanying diagram.



Each compartment (capacity 152 eggs) of the new multiple incubator is equipped independently with electric devices which allow wide range in the control of temperature, humidity, supply of fresh air, rate of mixing of air and turning of eggs. Beside that, a special provision is made for sampling and transferring of air to the laboratory for analyses. Accuracy in the control of temperature and humidity has been attained within an average, ± 0.2° C. and ± 1.0 per cent. relative humidity.

When the incubator is in operation, outdoor fresh air, regardless of atmospheric conditions, may be brought continually through the long pipe (1), in which it is heated to room temperature, by means of the blower (2), driven by the variable-speed motor (3). The speed of the motor is regulated by the control lever (4), a point of which is laid against the scale (5). The total rate of air flow is measured at the three-way valve (5a) by the gas meter (5b); then air is distributed at will by means of the valves (6), conditioned in respect to humidity in the humidifiers (7), and the actual amount of it in each compartment is determined at the three-way valves (8) by the gas meter (9). Indrawn air strikes the electric heater (10), which is controlled by a thermostat with mercury switch. The temperature is recorded by the right-angle thermometers (11) graduated to 0.2° C., and the humidity recorded by the precision hair hygrometers (12). Air in each compartment is evenly distributed over the hatching eggs by the air mixers (13), which have the pulleys (14) connected with the shaft (15) and, through the countershaft (16), to the low-speed electric motor (17). At any time samples of air may be drawn through the sampling tubes (18) and the selective valve (19) to the outlet tube (20) leading to a laboratory analysis apparatus. In order to prevent any accident from an electric power shutoff or disorder in circulation or mixing of air, special electric alarm systems are connected with the living quarters of the operator. The circulation of air is under the control of a system similar to that previously described;[2] but the mixing of air is controlled by the governor (21) connected with the mercury switch (22), the battery (23) and the electric bell (24).

The efficiency of the above-described laboratory incubator, as compared with the old incubator, is obvious. It provides: (1) greater accomplishment in

[4] A. L. Romanoff, Science, 60: 484, 1929.

[5] A. L. Romanoff, *Alabama Polytech. Inst. Bul.*, 25: 45–49. (Poultry Sci. Assn. Proc., 21: 45–49, 1929) 1930.

[6] A. L. Romanoff and A. J. Romanoff, *Biol. Bul.*, 57: 300–306, 1929.

[7] A. L. Romanoff, *Jour. Exp. Zool.*, 54: 343–348, 1929.

[8] A. L. Romanoff and A. J. Romanoff, *Jour. Exp. Zool.*, 56: 451–457, 1930.

[9] The data from two years of experimental work are ready for publication.

[10] The assembling of this laboratory incubator was made possible in part through the assistance of the Smith Incubator Company Fellowship Fund.

the experimental time, which is limited to the natural hatching season of the year; (2) simplicity in the routine work, due to many automatic devices; (3) uniformity in the seasonal quality of hatching eggs in each group of experiments; and (4) results of several experiments suitable for comparison, particularly in the study of the effect of various environmental factors on the developing embryo.

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SPECIAL ARTICLES

ON THE LAWS OF KINETIC SYSTEMS

THE general law of growth which populations tend to follow is well known. It is expressed graphically by Verhulst's "logistic curve," rediscovered by Pearl and Reed,[1] and may be stated as follows:

> While periodic renewal maintains its limited resources in matter and energy at one level, a population so multiplies that the proportional increase anticipated in absence of checks fails in the same measure as the attained fraction of the limiting population grows.

This is the master law of populations composed of a single sort of organism, populations in the ordinary sense, *simple* populations. Consider the damping effect of population upon its own growth-rate a measure of pressure, and the law may be stated more briefly. It is set down next in its concise form, with four additional laws derivable from it by inspection.

General law of simple populations: While periodic renewal maintains its limited resources at a constant level, the pressure in a population varies as the attained fraction of its limit.

Secondary laws: (1) When in a population the average individual energy is constant, pressure varies inversely as the volume occupied.

(2) In a mixed population each component exerts the same pressure as if it alone occupied the whole volume, and the total equals the sum of the several partial pressures.

(3) If the average energy of their units be the same, equal volumes of two populations under the same pressure contain the same number of individuals.

(4) At constant pressure the volume occupied by a population, and at constant volume the pressure in a population, varies as the average individual energy.

Here it must be stated that in applying the secondary laws of populations, or in testing their applicability to empirical data, one must always measure volume in appropriate units. In working with flies, for example, a pint bottle doubly charged with banana-agar may not be considered an experimental "universe" of twice the volume of a half-pint singly charged. The true two-unit universe is one composed of two half-pint bottles with a single charge each.

In the pint bottle doubly charged, the whole method of yeast culture, for use of the adult *Drosophila* population it largely supports, is changed by altering the relation between surface and volume of the substratum on which the yeast is grown. The result is just such as a revolutionary change in agricultural methods would entail in the growth of a human population. Or, again, the transfer of a fly population from two communicating half-pint bottles normally charged to a pint bottle doubly charged, if all the details of Pearl's culture method were followed throughout, should induce just such a change in the curve of population growth as occurred when Germany and Japan turned from agriculture to industry in the nineteenth century.[2] A change opposite in sign should probably follow the transfer of a similar population to four gill-bottles connected with one another and provided with half the standard charge each.

The situation may be seen more clearly if approached from another direction. Space, from the standpoint of the kinetic theory of gases, does not differ qualitatively from point to point. But from that of populations it has structure virtually imposed upon it; if not by the mode of distribution of sources of matter and energy, then by the distribution of opportunity for the disposition of population wastes. Thus to add unit to unit of volume, when dealing with simple populations, it is necessary to add to one structured system another quite like it; or, in effect, to measure volume in terms of the unit universe, be it what it may, rather than in standard cubic centimeters or inches.

Another point requires passing mention: The pressure in a population varies with the attained fraction of its limit; and the limit is fixed by the ratio between available maximum in some critical factor and individual need. But need and expenditure, intake and outgo, are merely the debit and credit sides of the organism's ledger account with energy. Hence the legitimate substitution of the term "individual energy" for "individual need" in the secondary laws of simple populations to which we now return.

These laws relate to one another four terms—pressure, volume, number and average individual energy. But these are the terms which appear in the gas laws, and the relations said to exist between them are precisely the same in the two cases. We must therefore

[1] *Proc. Nat. Acad. Sci.*, vi, pp. 275–288, 1920.

[2] Raymond Pearl, "Biology of Population Growth," pp. 19–21, 1925.