irregular external systems, and they are, in fact, not greatly unlike the average galaxy in luminosity and dimensions. It may be inferred from the studies at Harvard of the dimensions of the Milky Way[4] and of the Coma-Virgo galaxies, investigated by Miss Ames and the writer,[5] that the total mass of the approximately three hundred systems comprised in the Coma-Virgo cloud is comparable with the mass of our Galaxy. Our Galaxy, however, appears to be much more compactly aggregated than the cloud of galaxies in Coma-Virgo, which is loosely strewn throughout a region with a diameter probably five to ten times that of our galactic system. It remains for future investigation to see if theory or comparative observation can show how an enormous system such as ours may develop from (or into) a dispersed group like the Coma-Virgo cloud, with its individual members ranging in dimensions from objects smaller than the clouds of Magellan to spirals approximately as large as the Andromeda Nebula.

[1] Shapley, *Mt. Wilson Contr.*, No. 161, 20, 1918.

[2] Humason, these PROCEEDINGS, **15**, 167, 1929.

[3] Hubble, these PROCEEDINGS, **15**, 169, 1929.

[4] These PROCEEDINGS, **14**, 825–834, 1928.

[5] Shapley and Ames, *Harvard Bulletins* 864, 865, 866, 868, 869, 1929.

WATER-INTAKE AND ITS RELATION TO THE SURFACE AREA OF THE BODY

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Our knowledge of the factors involved in the regulation of the water-intake of man as well as of animals is still very limited. From the point of view of physiology much is known, of course, regarding the effect on the blood, the kidneys, and the tissues in general, of forced administration of water in various amounts; but from the point of view of the behavior of the entire organism—to what extent and how the animal itself regulates the water-intake—our knowledge is meager. It is with the solution of this problem that the present experiments are concerned.

Obviously it would be very difficult to determine what regulates the water-intake in man because of various current fads and deep-rooted notions regarding the efficacy or inefficacy of drinking large or small quantities of water. Therefore, recourse must be had to animals whose behavior is not influenced by such complicated factors.

Rats were used for this purpose since their thirst or drinking habits can be studied under very simple and satisfactory conditions. From observations made on fifty-one animals it has been determined how much the rat drinks from day to day over long periods of time, from the age of weaning well into middle age. Study of the graphs plotted from these data has made it possible to establish the principle which determines the water-intake of the rat and which may determine the water-intake of man as well.

Methods.—In these experiments the daily water-intake of fifty-one albino rats was measured from the 30th day (time of weaning) to the 160th day of life. Twenty-four males and twenty-seven females were studied. The animals were given free access to food and water throughout the experiment.

They were kept in separate cages of the type used in activity experiments and described in previous papers (Richter and Wang, 1926; Richter, 1927). Each cage consisted of a small living compartment large enough to hold a large rat, a food cup, and a water-bottle. Attached to the compartment was a revolving drum always accessible. The revolutions of the drum were recorded on a cyclometer.

The type of inverted water-bottle used was described in a previous paper on the effect of alcohol on activity and food-intake (Richter, 1926). Evaporation was reduced to a minimum because of the small area of water exposed to the air, and loss of water through spilling or leakage was entirely eliminated.

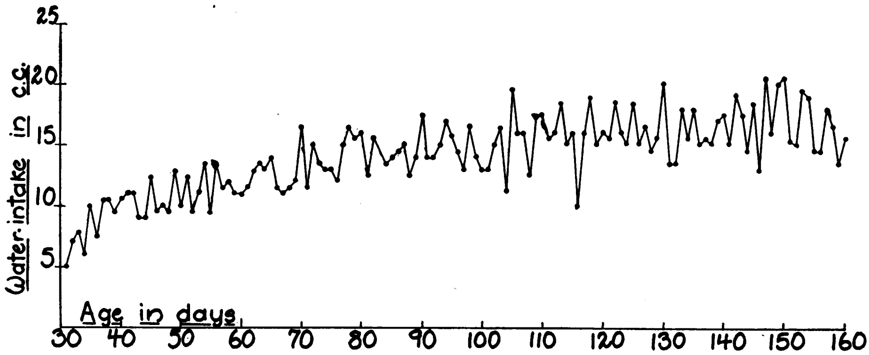
The temperature of the room in which the animals were kept varied between 72° and 78°F. averaging 75°F., except during a few weeks in the summer when it rose occasionally to 80°F. The humidity averaged about 70%, fluctuating between 50 and 90%.

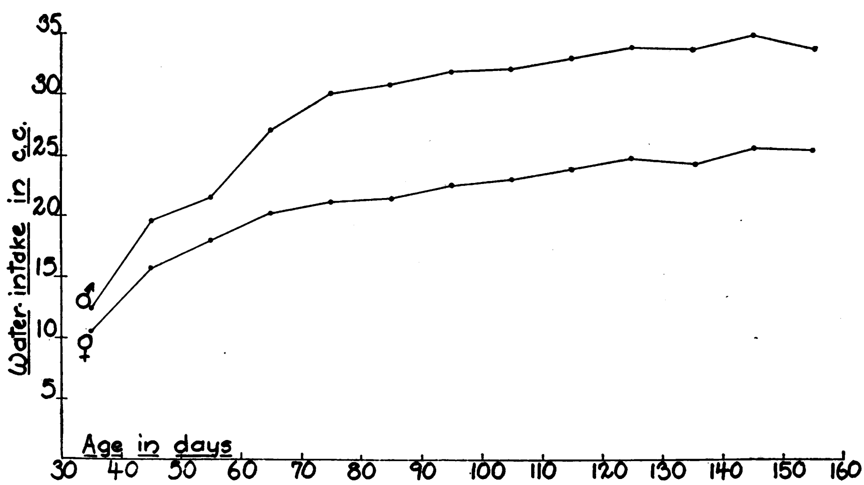
The food used in these experiments was the standard diet recommended by McCollum of the Johns Hopkins School of Hygiene, and was mixed per kilogram according to the following formula:

Graham flour	725 grams
Skimmed milk powder	100 grams
Casein	100 grams
Calcium carbonate	15 grams
Salt	10 grams
Butter	50 grams

The rats were allowed to eat as much of this dry food as they wished. Five grams of fresh lettuce, estimated to contain three cubic centimeters of water, were fed to each animal weekly. The diet used is thus described in detail in order that its dry nature may be emphasized and that its constant salt content may be borne in mind. Variations in water-intake referable to changes in the kind of food were ruled out in this manner.

Results.—The daily water-intake curve for a normal female albino rat is shown in figure 1-*a*. The ordinates give water-intake in cubic centimeters; the abscissae, the age of the animal in days. It will be noted that the water-intake increased gradually with age from 5 cc. at 30 days to about 17 cc. between 150 and 160 days. It will also be noted that although the general shape of the curve is fairly regular, there is con-





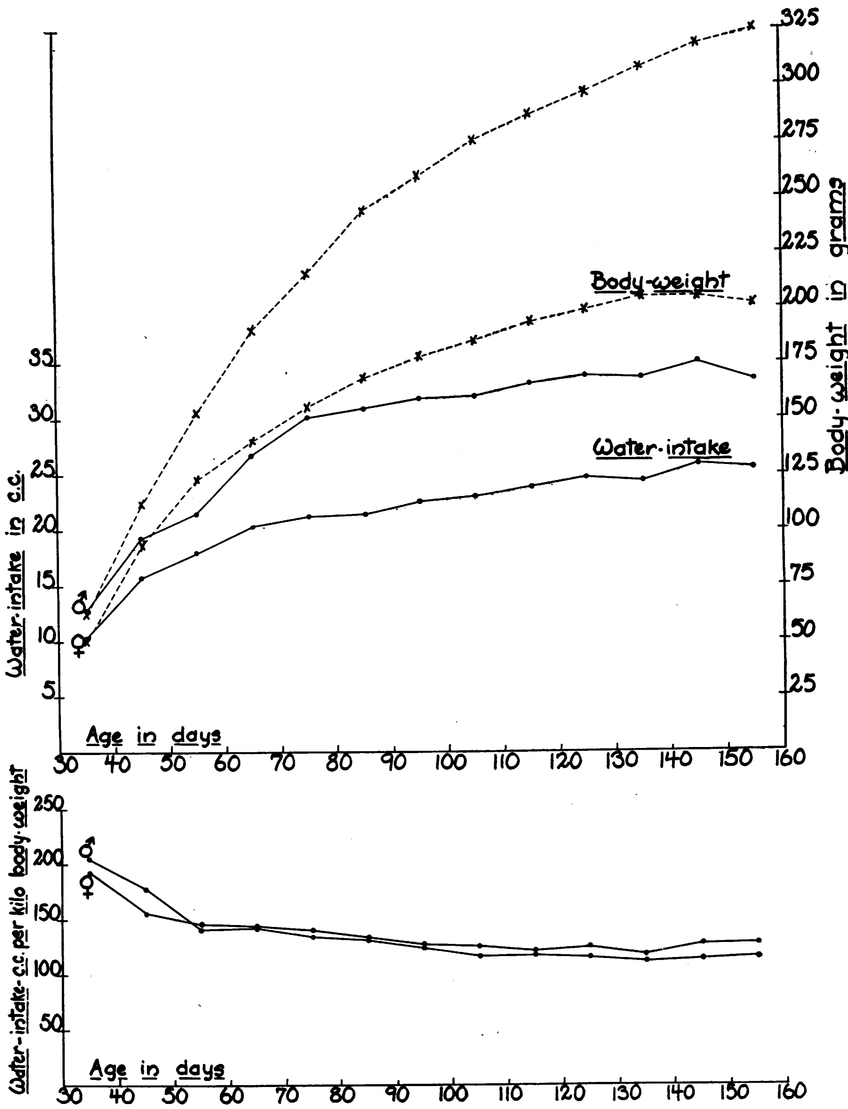
FIGURES 1-A AND 1-B

Fig. 1-*a*. Typical daily water-intake curve for a female rat between 30 and 160 days of age.

Fig. 1-*b*. Average daily water-intake curves for twenty-four male and twenty-seven female rats calculated for ten-day periods.

siderable fluctuation in the water-intake from day to day. The range of fluctuation is rarely more than 5 cc., however.

The average intake in cubic centimeters calculated in ten-day periods for the twenty-four males and twenty-seven females is shown in the curves in figure 1-*b*. Between the 30th and the 40th days the average daily intake is 19.5 cc. for the males, and 15.8 cc. for the females. These values increase to 33.5 cc. for the males and 25.5 cc. daily for the females



FIGURES 2-A AND 2-B

Fig. 2-*a*. Graphs showing the relationship of average daily water-intake to body-weight for an equal number of male and female rats from 30 to 160 days of age.

Fig. 2-*b*. Graphs showing water-intake per kilo body-weight for the same groups of males and females.

between the 150th and 160th days of life. Besides the increase of fluid intake with age, it is very important to note the fact that the males drink more than the females.

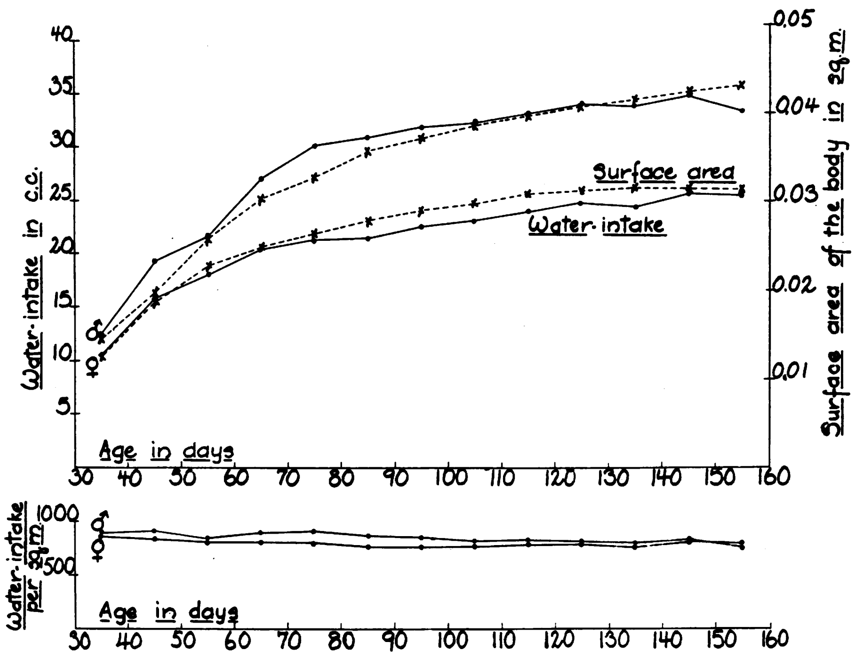
The gradual increase in water-intake which seemed to parallel the growth of the animal suggested that there might be some relation between water-intake and body-weight. The larger water-intake of the males, which grow more rapidly and become larger than the females, was also suggestive of the presence of such a relationship. In order to test this suggestion the curves shown in figure 2-*a* were prepared. They show the water-intake in cubic centimeters just as in figure 1-*b*, but in addition they show the body-weight curves with scales adjusted so that the two sets of curves start as nearly as possible at the same point. It can be seen that the body-weight increases much more rapidly than the water-intake, so that at 160 days there is a wide difference between the water-intake and body-weight curves. This discrepancy can be seen also when the water-intake is calculated per kilogram of body-weight as in figure 2-*b*. There is a very sharp drop in the curve from 30 to 60 days, and a moderately sharp drop from 60 to 130 days After that it appears to reach a more or less constant level of about 150 cc. per kilo.

It must be noted that the difference in water-intake between males and females almost disappears when the intake is calculated per kilo body-weight. In fact, after the first 60 days, the males drink slightly less per kilo body-weight than the females.

From all of these figures, then, it becomes clear that water-intake does not bear a direct and simple relationship to body-weight. It must be dependent on some other factor. The next relationship which suggests itself is with surface area. This was calculated from the body-weight by means of Meek's formula, using Rubner's constant for the rat—$0.091\sqrt{W^2}$ (Lusk, 1928). Figure 3-*a* shows again the absolute water-intake in cubic centimeters as in figure 1-*b*, and in addition the average surface area of the male and female rats between 30 and 160 days of age. The scale for surface area curves was calculated so that the initial ordinates for surface-area and water-intake would be approximately the same. The top lines are for the males. It can be seen that, very differently from the body-weight curve, the surface area curve coincides almost exactly throughout with the curve for water-intake. The same is true for the females. The curves parallel each other as closely as one could expect in any physiological relationship.

This correlation between water-intake and surface area can be seen in the curves in figure 3-*b*, where the water intake is calculated per square meter body-surface. Here the curves or t he males and females are almost flat lines from 30 to 160 days, averaging about 800 cc. per square meter of body-surface. There is some slight difference between the males and females during the early part of the experiment, but after 110 days the curves come together closely. In ten additional animals we were able to show that this level is maintained constantly for at least 560 days. The animals were killed at that time, but it is probable that the intake would have remained the same for some time longer.

It is interesting to note that when these water-intake figures for the rat calculated per square meter of body-surface are applied to man, we obtain a figure of 1400 to 1600 cc. per day, which is generally believed to be the normal water-intake for man. When the water-intake for man is calculated on the basis of the per kilo body-weight intake in rats, about 8500 cc. is obtained for the average adult, which far exceeds the actual intake except under pathological conditions. It may be that this relationship between water-intake and surface area will hold generally for other mammals besides the rat and man.



FIGURES 3-A AND 3-B

Fig. 3-*a*. Graphs showing the relationship in the rat between average daily water-intake and surface area of the body between 30 and 160 days of age.

Fig. 3-*b*. Graphs showing water-intake per square meter of surface area.

Discussion.—It was shown above that the amount of water that the rat drinks is determined under ordinary conditions by its surface area. The question arises at once as to the significance of this observation—why should this be so? We may say at the outset that there are no data at hand by means of which a fully satisfactory answer to this question can be given. There are, however, two possibilities which we should like to mention and which may help to clarify the issues for further experimentation.

The explanation which occurs most readily, particularly to those familiar with work on metabolism, is that water-intake must be dependent on the metabolic rate which is known to be proportional to the body-surface. Water-intake would bear only an indirect relationship to body-surface according to this view; that is, body-surface would determine metabolic rate, and metabolic rate would in turn determine water-intake.

The second explanation of the relationship of water-intake to body-surface is concerned with the temperature control of the body. The chief heat-regulating functions of the skin have to do with radiation and conduction of heat and the gradual elimination of moisture by evaporation. It is to the last of these functions that we might expect water-intake to be related.

The facts favoring and opposing these two views may now be considered. So far as the first view is concerned the evidence that we have indicates that water-intake under ordinary conditions is not dependent on metabolism. To begin with it is known that young animals have a higher metabolic rate than adult animals calculated per square meter surface area. Despite this higher metabolic rate we have just shown that the water-intake is the same for a 30-day old animal as for an animal 130 days or even 560 days old. So, also, the water-intake per square meter surface in the female is the same as that of the male, although the metabolism of the female is considerably more rapid.

The evidence in favor of the view that water-intake is determined by the evaporation of water is limited but still quite suggestive. As a basis for this discussion it must be made clear that it is now well known that rabbits and other animals like the rat, which apparently do not have any sweat glands at all, do give off a considerable amount of moisture each day in the form of insensible perspiration (Richardson, 1926; Eimer, 1927), and that the amount of moisture given off is not influenced to any noticeable extent by the presence of the hair on the skin, since an equal amount is given off after all the hair has been clipped away.

The importance in the rat of this means of water elimination can be made clear when we see what a large difference there is at ordinary temperatures (75° to 78°F.) between the amount of water eliminated in the urine as compared to the total water-intake. We have found that only about one half or less of the water consumed leaves the body through the kidneys. The rest must leave either through the lungs or the skin. According to Meyer's formula (1925) all mammals eliminate in the form of insensible perspiration 40 grams of water per hour per square meter of body-surface. On this basis the rat should eliminate 960 grams per day per square meter in this way. This figure is rather high, since the rat does not drink that much daily. There can be no doubt, however, that a large amount of the fluid intake is eliminated as insensible perspiration. Judging from what is known from comparable experiments on man, who eliminates about 750 to 800 cc. per day as insensible perspiration, about two-thirds will leave through the skin and the remaining one-third through the lungs. This is a surmise, of course, since the only definite reason we have to believe that the same proportions that hold for man will hold also for the rat is the fact that the same law of water-intake which applies to the rat apparently applies also to man. From preliminary experiments performed with this end in view, we have learned that water-intake as well as water-elimination in the form of urine or insensible perspiration shows an almost incredible sensitivity to so-called psychic stimuli, which would make efforts by ordinary means, measurements in closed boxes, etc., used in work on rabbits, of rather doubtful value. The problem becomes somewhat more perplexing in view of the claim of Benedict and Root (1926) that there is a close correspondence between insensible perspiration and metabolic rate.

In any case, it will be very interesting to determine definitely why it is that under ordinary conditions the amount of water taken daily is determined by the surface area.

Summary.—1. The daily water-intake of fifty-one rats, twenty-four males and twenty-seven females, was measured from the age of 30 to 160 days. The intake increases gradually with age and is larger in the males than in the females. For males it is 19.5 cc. at 30 days and 33.5 cc. at 160; for the females 15.8 cc. at 30 days and 25.5 cc. at 160 days.

2. An attempt was made to correlate the water-intake with the body-weight inasmuch as it seemed to increase with body-weight and because the males, which are larger, drink more. This attempt was unsuccessful. Water-intake increases much more slowly than body-weight. Young animals drink more per kilo body-weight than adults. For adults the the average intake per kilo is 150 cc., which when calculated for man would be 8500 cc. This is much higher than 1500 cc. which is generally regarded as a good average.

3. It was found, however, that water-intake is very closely correlated with body-surface. The curves for body-surface and water-intake coincide perfectly throughout the entire period over which these experiments were carried on. When water-intake is calculated in terms of square meter of surface, the intake is about 800 cc. per square meter at all ages from 30 to 160 days, and when calcuated for man amounts to 1500 cc., which is very close to the expected average.

4. The possible significance of these observations was discussed in

terms of the relation of water-intake to metabolism, and to moisture lost through the skin in the form of insensible perspiration.

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THE INFLUENCE OF THYROID GLAND FEEDING ON THE ACCELERATION OF THE GROWTH OF LARVAE OF DROSOPHILA MELANOGASTER

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This question has attracted the attention of many investigators since 1908 when M. Nowikoff[1] published the first paper dealing with the influence of hormones of vertebrates upon the organism of invertebrates. In spite of that in a recent review of this literature by Hahn[2] only five papers are mentioned which show positive evidence of the effect of thyroid substances upon invertebrates. The authors of the papers are: Kunkel (1918), Abderhalden (1919), Vecchi (1920), Terao-Wakamori (1924) and Kopeč (1924).[3] Only Kopeč's material has been worked out from a statistical point of view and gives us, therefore, the right to conclude that the feeding with addition of thyroid substances diminishes the weight of the chrysalids *Limantria dispar* L. The results of other numerous investigations cannot be taken into a serious consideration because of two reasons. First of all, most of the authors are evidently very little informed about the natural history and the normal variations of vital functions of the animals studied, and second they do not apply statistical methods in the process of working out the collected data.

In our attempts to solve this problem we tried to overcome both of these defects. As material we took larvae of Drosophila whose normal growth and variation have been thoroughly described in our previous paper.[4] In this investigation we used the same methods of collecting, preserving, and measuring the larvae as before. The thyroid substance was used in the form of powdered hog thyroid containing 0.42 per cent