equations by the method of least squares, are, respectively, 0.340 and 0.356. The error, due to the use of the rapid method of fitting the curves, was less than one per cent. in each case, which is undoubtedly well within the limits of the experimental error involved.

The chief source of inaccuracy in the rapid method of fitting the curves probably lies in using the gains in live weight, per unit feed eaten, over finite intervals of time as approximations to the values of the derivative, $\frac{dW}{dF}$. If the chickens used in the writer's study had been weighed at less frequent intervals, the rapid method probably would not have yielded quite such accurate results.

The advantages of this method over the method of arithlog plotting are the elimination of the errors of judgment, which are inherent in the latter, and the fact that the value of the constant, C, which is of particular interest if the curve is used to interpret the results of a feeding experiment, can be determined directly.

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THE EFFECT OF THE APPLICATION OF A FIELD OF ATTRACTION TO A GAS

CONSIDER a gas of molecules, or electrons, in a shallow vessel having two of its plane walls parallel to each other. The vessel is placed in a field of attraction with these walls at right angles to it. Let us suppose that the conditions are such that a molecule on moving from one of these plane walls to the other has little chance of undergoing a collision with another molecule. Hence when a molecule moves from one of the plane walls to the other against the field, it undergoes a decrease in velocity, while when it moves in the opposite direction its velocity undergoes an increase. Hence the molecules impinge and rebound from one of the walls with a greater velocity than is the case at the other wall. Now the velocity of rebound[1] is an index of the temperature of the gas close to the wall; and hence under these conditions there will be a continual transference of heat from one wall to the other. But this is thermodynamically impossible. It follows therefore that the molecules must undergo certain changes compensating for this effect of the field. The occurrence of inelastic collisions of the molecules with the walls can not, it will be found, by themselves explain the effect. If, however, we suppose that the molecules possess certain properties previously deduced in other ways,[2] this effect can be compensated for. These properties are: (a) A molecule, or electric charge, slows down when moving freely, and absorbs radiant energy in the process which is stored up as internal energy; (b) potential energy of attraction, or repulsion, may become internal energy, and *vice versa;* (c) internal energy may also be directly converted into radiation.

We may now suppose that the internal energy accumulated by a molecule during its motion according to (a) and (b), is mainly converted into potential energy of repulsion according to (b), and this into kinetic energy, at the wall where the molecules arrive with a decrease in velocity. This is to take place in such a manner that the average velocity of collision is reduced at one of the walls and increased at the other, so that the temperature is the same at both walls.

If a different explanation of the difficulty is possible, I shall be glad to hear about it.

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SCIENTIFIC APPARATUS AND LABORATORY METHODS

THE IOWA EYE-MOVEMENT CAMERA

MANY efficient cameras for photographing eye movements have been built since the inauguration of the corneal reflection method of eye photography by Dodge in 1901. The first cameras obtaining a continuous record of eye movement recorded only the horizontal movements of one eye. Dearborn made an advance by recording the vertical movements of one eye on a horizontally moving film and the horizontal movements of the other eye on a vertically moving film. The camera herein described obtains simultaneous binocular records of both vertical and horizontal movements.

The light used to produce the corneal reflection for photographing is a direct current Bausch and Lomb automatic carbon arc. This light, screened from the view of the reader, is placed at right angles to the eyes as is illustrated in Fig. 1. The light is focussed by a large condensing lens on a diaphragm which allows only the center of the light from the positive carbon to pass on. Between the light and the diaphragm is a chopping disc operated by a synchronous motor which interrupts the beam of light fifty times

[1] Apart from the increase caused by the attraction of the wall. R. D. Kleeman, *A Kinetic Theory of Gases and Liquids*, John Wiley & Sons, New York.

[2] R. D. Kleeman, *Phil. Mag.*, 7: 493, 1929; *Nature*, 124: 728, 1929; SCIENCE, 70: 478, 1929; 71: 340, 1930; 72: 224, 1930; *Z. anorg. u algem. Chemie*, 196: 284, 1931; *Z. Electro-chemie*, 37: 77, 1931; 37: 371, 1931.

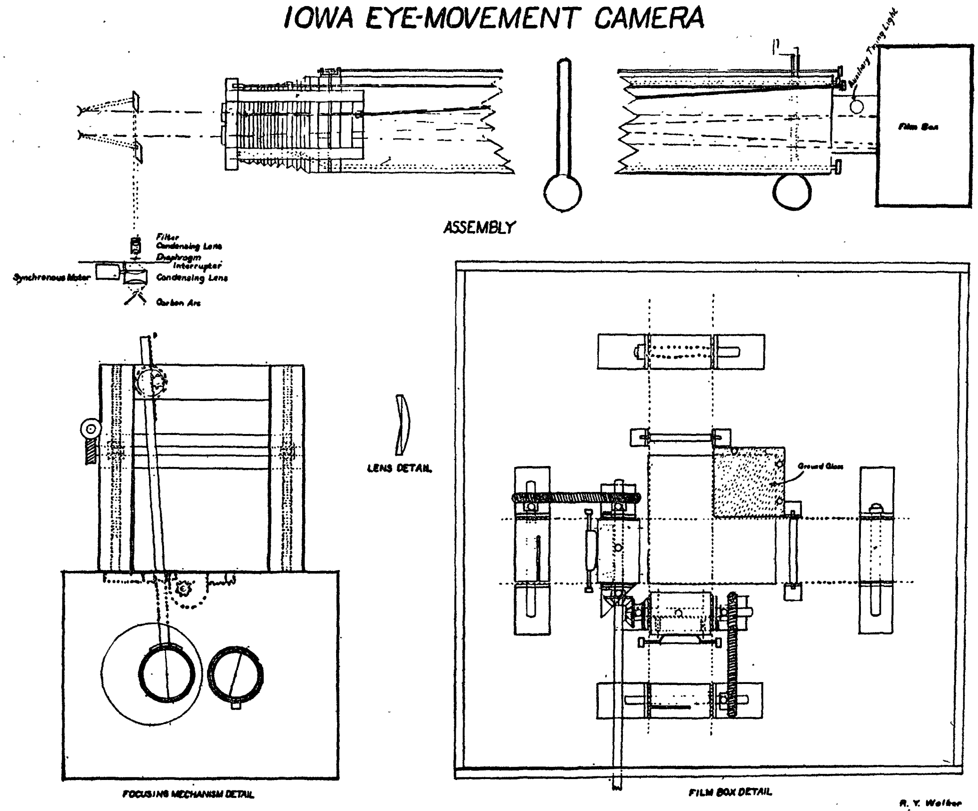

FIG. 1.

a second. The rays of light passing through the diaphragm are converged to a pencil beam by a second lens. The beam then passes through three cobalt blue filters before being reflected from two adjustable first surface mirrors to the eyes.

Since this camera requires that the light reflected from each eye be recorded on two papers it was necessary to introduce a system of dividing the light beam from each cornea into two beams. With the aid of the local branch of the Riggs Optical Co. a pair of prisms were ground and mounted with Canada balsam base out on the plano surfaces of 2.5 diopter, 35 mm diameter crown glass lenses. The prism strength of the left lens was 1.25 degrees, the right lens 1.5 degrees. The difference in strength is necessary to permit the proper aligning of the reflected beams on the recording paper.

The entire lens unit is mounted so that it may be adjusted in three dimensions. Vertical and depth adjustments are made by racks and pinions on the lens mounting. Horizontal adjustments are made by a worm at the rear which pivots the entire camera box. The lens for the left eye is adjustable independently in the horizontal and vertical by means of racks and pinions as illustrated in the focussing mechanism detail (Fig. 1). All lens adjustments are made from the rear by means of telescoping rods.

The lenses, mounted approximately 20 cm from the eyes, focus the reflections from the corneas at the end of the camera box which is about 180 cm from the lens mounting. This amplifies the movement nine times and permits the use of weak prisms, thereby insuring a sharp focus.

Eastman No. 1 recording paper, $1\frac{7}{8}$ inches wide, is moved synchronously in the vertical and horizontal directions by the mechanism illustrated in the film box detail (Fig. 1). Spiked traction rollers insure positive movement of the paper between the guide rollers to the windup rollers. A constant speed motor with a variable reduction gear is used for driving power. A satisfactory rate of speed for most records is from 7 to 9 cm per second. Good records may be obtained at speeds up to 20 cm per second.

To facilitate focussing a piece of ground glass was mounted in one quarter of the aperture of the film box. When a correct focus is obtained a slight shift of the camera in the horizontal and vertical places the beams of light in their proper place on the recording paper.

A mercury filled neon glow lamp is used as an auxiliary timing light or signal marker. The light, located in the rear of the camera, as indicated in the assembly (Fig. 1), passes through a slit dia-

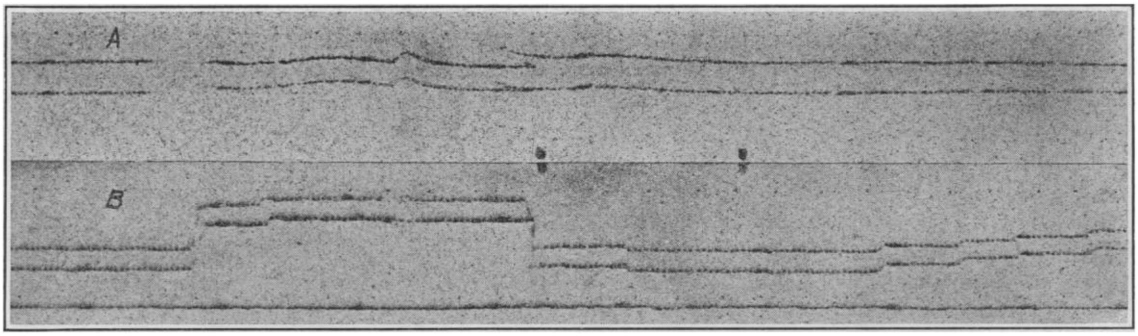

FIG. 2. Record A is the horizontal moving film which records the vertical movements of both eyes. The two upper lines in record B record the horizontal movements and the base line records the head movements on the vertical moving film. The strips of recording paper in this record are reduced from 1⅜ inches.

phragm and a condensing lens and is reflected from a mirror on the base of the inner side of the box to a focus across the intersection of the two recording papers. A perfect matching of the two records is thus made possible by matching the lines made on both records by a single light. This light may be flashed at regular intervals as an auxiliary timing device during reading movements, or it may be used to indicate the exact time of appearance of various other types of visual stimuli, or to indicate any other phenomena to be especially noted on the record.

The sample record in Fig. 2 shows the vertical and horizontal movements of the eyes in horizontal fixation movements and in the beginning of the reading of printed material. The first horizontal movement (reading from left to right) in record B is that of the eyes moving from left to right between the two fixation points placed above the first and last letter of the first line of the printed material. .78 mm movement on the record represents 1 degree of angular eye movement. The movement is indicated in record A by the spreading of spots due to the beams of light moving in the opposite direction to that of the recording paper. The next curve in record A indicates a marked upward twitch of the eyes of .1 second duration. The next movement indicated in both records is the return sweep from right to left preparatory to the beginning of reading. Since this movement is made in the same direction and faster than the movement of the recording paper it is indicated on record A by an overlapping of the lines of spots. The succeeding part of the record is that of a long fixation at the beginning of the line and the saccadic movements and fixation pauses during reading.

The base line of head movements in record B is obtained by recording the reflection from a steel ball mounted on a spectacle frame worn by the reader. The two adjacent marks on both records are produced by the signal marker mentioned above.

There are two methods of obtaining time measurements on this record: (1) The duration of any single movement may be measured by counting the number of small spots contained in that movement, each spot being equal to .02 second. These small spots are produced by the interruption of the light beam by the chopping disc described above. (2) Gross measurements may be made by measuring the length of record made by any movement and converting them into time measurements according to the speed of the recording paper. The exact speed of the paper may be continually checked by measuring the distance between the dashes in the record which occur twice a second. These dashes are produced by removing two of the interrupters in the chopping disc. This disc carries 25 interrupters (23 with the 2 omitted) and revolves twice a second, hence the dashes appear twice a second and are .05 second long.

In studying binocular coordination it is necessary to know the position on the record of one eye relative to the other. The dashes in the record, since they are produced by an interruption of the light previous to any division of the beam, make the relative position of the two eyes clear throughout the record.

The large cost of many of the satisfactory eye-movement cameras now in operation has heretofore prohibited their use in several laboratories. The cost of the materials used in the construction of this camera amounted to less than one hundred and fifty dollars. The use of recording paper costing about one cent a foot is an additional saving in expense as well as an aid in reading. The entire mechanism was built in a good laboratory shop by graduate students who were not skilled mechanics.

In summary the advantages of the Iowa Eye-Movement camera may be stated as follows: (1) Simultaneous recording of binocular horizontal and vertical movements; (2) the production of positive record of sufficient magnification for easy reading; (3) readily adaptable to various types of eye-movement problems other than reading; (4) low cost of construction and operation.

The problems for which this camera is now being used are: (1) The study of binocular coordination in convergence and divergence movements of alternate fixation on near and far points of light; (2) the analysis of eye movements of good and poor readers who have the same intelligence rating; (3) the determination of the attention value of different types of advertisements and of different items in a single advertisement; (4) analysis of changes that take place in eye-movement habits of poor readers who have been subjected to intensive remedial training; (5) binocular coordination of stutterers *versus* that of normal speakers, and (6) dysintegration of eye-movements during stuttering spasms.

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SPECIAL ARTICLES

THE GREAT GLACIAL CYCLE

IT is fairly well known that the present Ice Age, or the cycle of ice ages in an interglacial period of which we now live, was preceded by other ages or cycles of ages, leading as far back as we can see in geological history.[1] Some of these have been limited in extent, both of time and area, but others have involved large areas of the earth for millions of years. If we consider the greater cycles that are most recent and most certainly identified, and compare them with the absolute dates which have been obtained from radioactive changes,[2] we find that they occurred at intervals of some 200,000,000 years. Thus we may make the following comparisons, giving the periods in millions of years. I have used a unit of 210 millions, as it seems to fit a little better than the even 200, especially at the Cobalt glaciation, but the uncertainty of the data makes the difference trivial.

210. *Permocarboniferous Glaciation*

204. Joachimstal pitchblende, supposed Permocarboniferous.

239. North Carolina uraninite, supposed late Carboniferous.

A very long and widely distributed glacial period, mainly in the southern hemisphere and lasting through the later Carboniferous and much of the Permian, with its climax at the beginning of the Permian.

420. *Late Ordovician Glaciation*

374. Branchville, Ct., uraninite; Silurian or Devonian.

443. Lake Superior coracite; early or middle Ordovician.

This cycle is not so well defined, but seems to cover larger area in Quebec, and is also represented in Europe.

630. *Early Cambrian or late Precambrian Glaciation*

573. Katanga pitchblende; late Precambrian.

587. Ceylon thorianite; late Precambrian.

673. Morogoro, Tanganyika; late Precambrian.

This shows a very large area of glaciation in the world, but much of it is of uncertain date and may belong to the following period; back from this time fossil dating is no longer possible, and it becomes difficult to join up dated igneous rocks with the corresponding glacial deposits, except where, as at Cobalt, they are directly associated.

840. *Keweenawan*

No dated radioactive rocks; Reeds gives this as the date for the Keweenawan, which shows doubtful glacial remains about Lake Superior.

1050. *Cobalt (Huronian)*

987. Olary, S. Australia; Animikian.

1024. Ontario uraninite; Animikian.

1056. Arendal, Norway, cleveite; Cobaltian.

1087. Llano Co., Texas, uraninite and Douglas Co., Col. Samarskite; Cobaltian.

This is evidently a major glaciation at least in Canada, where the Cobaltian radioactive dated rocks and glacial remains are directly associated. Coleman discusses the Animikian as Precambrian and the Cobaltian as Huronian, but the radioactive dating suggests a single cycle. Extensive glacial traces elsewhere may belong to this cycle.

1260. *Algoman*

No dated glacial remains.

1470. *Timiskamian*

1465. Keystone, South Dakota, uraninite, Timiskaming.

Extensive glacial traces in Canada, doubtful elsewhere.

1680. *Keewatin*

Doré conglomerate of Canada a possible representative of this or an earlier cycle. No radioactive dating, so far as I know.

Plaskett[3] has just estimated that it takes the solar system 230,000,000 years to make the great circle around the system of the Milky Way. The rough agreement suggests a connection. It is well known that at present the dense center of the Milky Way

[1] A. P. Coleman, "Ice Ages, Recent and Ancient," New York, Macmillan, 1926.

[2] Holmes and Lawson: *Am. Jour. Sci.* (5) 13: 327, 1927, brought up to date and diagrammatically presented by C. A. Reeds, *Nat. Hist.* 31: 129, 1931.

[3] *Proc.* Am. Phil. Soc., 69: 417, 1931.