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Scope and Method of Study: The purpose of this investigation is to make a scientific study into the field of electrospherics and magnetospherics. These two words are new in the field of Physics and were coined by A. D. Moore, Professor of Electrical Engineering, University of Michigan, Ann Arbor, Michigan.

In the field of magnetospherics, an attempt is made to determine and record the various affects that an electromagnetic field (produced singly and in aggregate by electromagnets to be described in the report) of varying controlled intensity has on groups of magnetized and unmagnetized steel balls ranging in size from 0.007" in diameter to 0.375" in diameter.

In the field of electospherics, we will study the affects that an electrostatic field has on unmagnetized steel spheres.

A variety of coil arrangements and spacings will be employed as well as varied ball arrangements and different mediums of ball operation.

Findings and Conclusions: A great variety of formations and activities by the steel spheres resulted from the interaction of the various sized spheres with electromagnetic and electrostatic fields of varying intensity. Most of these phenomena are understandable in terms of scientific principles known to exist in such situations.

ADVISER'S APPROVAL L. Herbert Bruneau

INVESTIGATIONS IN MAGNETOSPHERICS AND ELECTROSPHERICS

By

DAVID GRAY JOHNSON

Bachelor of Science

University of Kansas

Lawrence, Kansas

1951

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INVESTIGATIONS IN MAGNETOSPHERICS

AND ELECTROSPHERICS

Report Approved:

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PROBLEM TO BE INVESTIGATED

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A great variety of formations and activities by the steel spheres resulted from the interaction of the various sized spheres with electromagnetic and electrostatic fields of varying intensity. Most of these phenomena are understandable in terms of scientific principles known to exist in such situations.

A LIST OF APPARATUS USED

Circular coil "A"
105 turns of #17 enameled electromagnet wire
4.340 inside diameter; impedance to 60 cycle-1.03 ohms

Circular coil "B"
150 turns of #17 enameled electromagnet wire
5.625 inside diameter; impedance to 60 cycle-2.3 ohms

Spherical steel balls
Commercial ball bearings, diameters-3/32", 1/8", 1/4", 3/8"
Spheroidal shot furnished by Pangborn Corporation, Haverstown, Md. These shot vary in size, with 85% falling between a ±0.005 tolerance of the following diameters: 0.007"; 0.016"; 0.033"; 0.064".

Variac - 115 volts, 60 cycle A.C., 10 ampere rating

Rheostat - 5.4 amps, 12 ohms

Strong permanent magnet

Stop watch

Voltmeter - 15 volts A.C. full scale

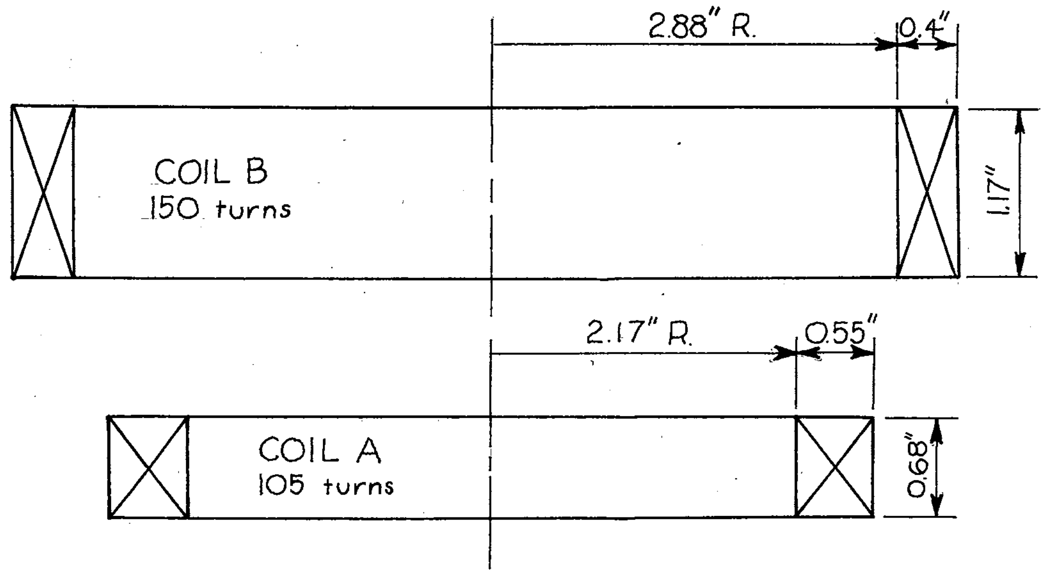
Ammeter - 10 amps A.C. full scale

Stroboscope

Polyethelene plastic bowls, approximately 3½" diameter

COIL DIMENSIONS

Scale: 3/4" 1'



INVESTIGATION I

Problem: Performance characteristics of the coils

Apparatus: Coil A, coil B, variac, rheostat, voltmeter - 15 volt, ammeter - 10 amp

Procedure:

Schematic of Connections

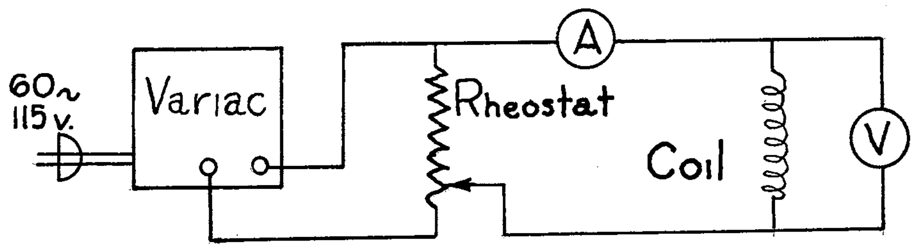


FIGURE 1

1. With the variac set at 20 volts and Coil A in the circuit, three different readings of voltage and current were obtained and recorded by varying the rheostat.
2. This procedure was repeated, with Coil B only in the circuit.
3. The same procedure was again followed with Coil B on top of, and separated from Coil A with a glass plate 0.230 inches thick, as shown in Figure 1. Readings were taken with the following different connections:
   a. Coils in series with the fields aiding
   b. Coils in series with the fields opposing
   c. Coils in parallel with the fields aiding
   d. Coils in parallel with the fields opposing

4. Procedure 3, on preceding page, was repeated with the coils in wide coupling. This was obtained by placing the glass 0.6" above Coil A using three insulating spacers, and then placing Coil B 1.05" above the glass in the same manner.

DATE AND COMPUTATIONS

COIL CONNECTION	V	I	Z calc.	Z average
Coil A Only	5.5 2.2 0.9	5.0 2.0 1.0	1.1 1.1 0.9	1.03
Coil B Only	12.0 8.0 3.25	5.0 3.5 1.5	2.4 2.3 2.2	2.3
Coils A & B in Series Close Coupling Fields Aiding	15.0 10.0 6.0	3.74 2.5 1.5	4.01 4.0 4.0	4.0
Coils A & B in Series Close Coupling Fields Opposing	15.0 10.5 4.25	5.0 3.5 1.5	3.0 2.9 3.1	3.0
Coils A & B, Parallel Close Coupling Fields Aiding	4.0 2.56 1.2	5.0 3.0 1.45	0.8 0.85 0.83	0.83
Coils A & B, Parallel Close Coupling Fields Opposing	3.0 2.0 1.0	4.65 3.18 1.6	0.65 0.65 0.66	0.65
Coils A & B in Series Wide Coupling Fields Aiding	15.0 11.0 6.0	4.15 3.1 1.75	3.6 3.7 3.5	3.6
Coils A & B in Series Wide Coupling Fields Opposing	15.0 10.0 5.0	4.6 3.11 1.6	3.3 3.3 3.2	3.3
Coils A & B, Parallel Wide Coupling Fields Aiding	3.0 2.0 1.0	3.8 2.6 1.3	0.78 0.77 0.77	0.77
Coils A & B, Parallel Wide Coupling Fields Opposing	3.0 2.0 1.0	4.27 2.95 1.48	0.72 0.68 0.67	0.69

INVESTIGATION II

Problem: To determine the effects on magnetized steel balls of various sizes by an electromagnetic field produced when Coil B is placed above Coil A and separated by a glass plate.

Apparatus: Coil A, Coil B, glass plate 8" by 8" by .25", variac, voltmeter, ammeter, steel balls of diameters 3/32", 1/8", 1/4", 3/8".

Procedure:

1. Six balls of each size were magnetized by placing them on the poles of a permanent magnet for 24 hours.
2. The apparatus was hooked as shown in Figure 2 and connected with the coils in series with the fields opposing.
3.

Coil Arrangement

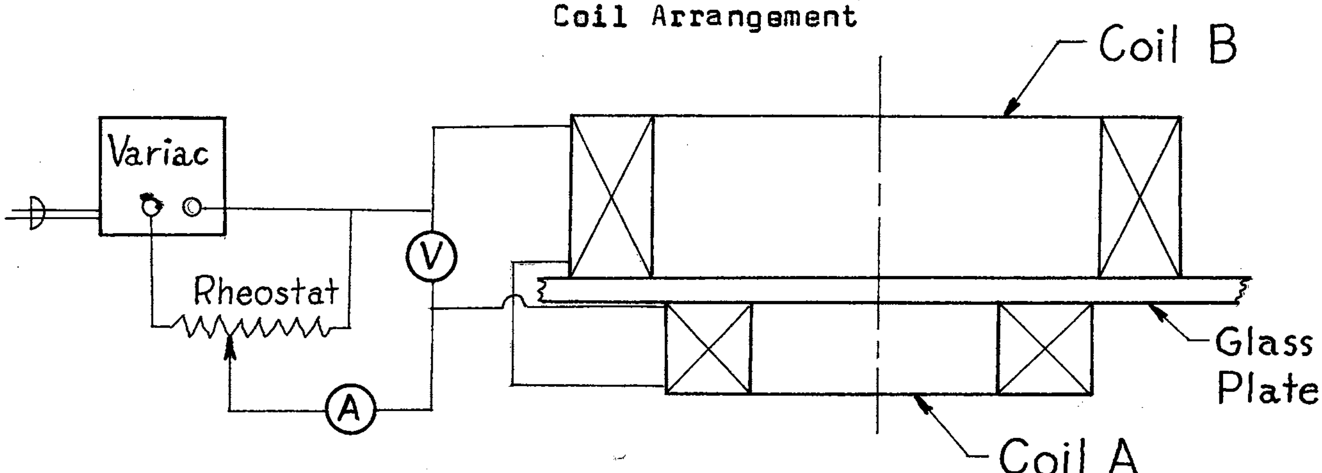


FIGURE 2

4. The variac was set at 20 volts and the rheostat set so that no current was flowing through the coils.

Magnetized balls, 3/32" in diameter were placed on the glass plate, inside Coil B. The current through the coils was slowly increased by sliding the rheostat contact.

5. This procedure was repeated, using magnetized balls 1/8" in diameter.
6. The procedure was repeated, using magnetized balls 1/4" in diameter.
7. The procedure was repeated using magnetized balls 3/8" in diameter.
8. The entire procedure, steps 4 to 7, was repeated after connecting the coils with their fields aiding.
9. In order to establish the direction of the field at the base of the inner circumference of Coil B and the spin axis of the rotating balls, three methods of procedure were employed.
   a. The first consisted of placing unmagnetized steel balls 0.016" in diameter on the glass plate in Coil B. The standard current of 3 amperes was then applied. The balls, magnetized by induction, were then attracted to the bottom circumference of Coil B and formed short strings tilted up at the end, toward the center of Coil B, at about a 45 degree angle, thus indicating the resultant direction of the fields at that point. This is shown in Figure 4.

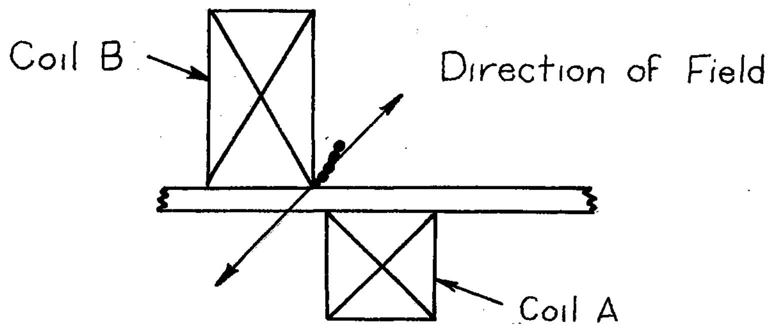


FIGURE 4

b. Secondly, if with no field applied, the ball is started with a push with the finger, the spin axis would have to be inclined at some angle since the ball makes contact at two points, floor and wall, unless the three forces involved were greatly out of balance and causing slippage at one of the two contact points. Horizontally, there were centrifugal, frictional, and magnetic forces acting on the ball, and vertically, there were gravitational, frictional, and magnetic forces acting. If these forces approached equality resultants in both directions, a spin axis tilted at 45 degrees should result. Evaluation and calculation shown later indicated an approximate balance.

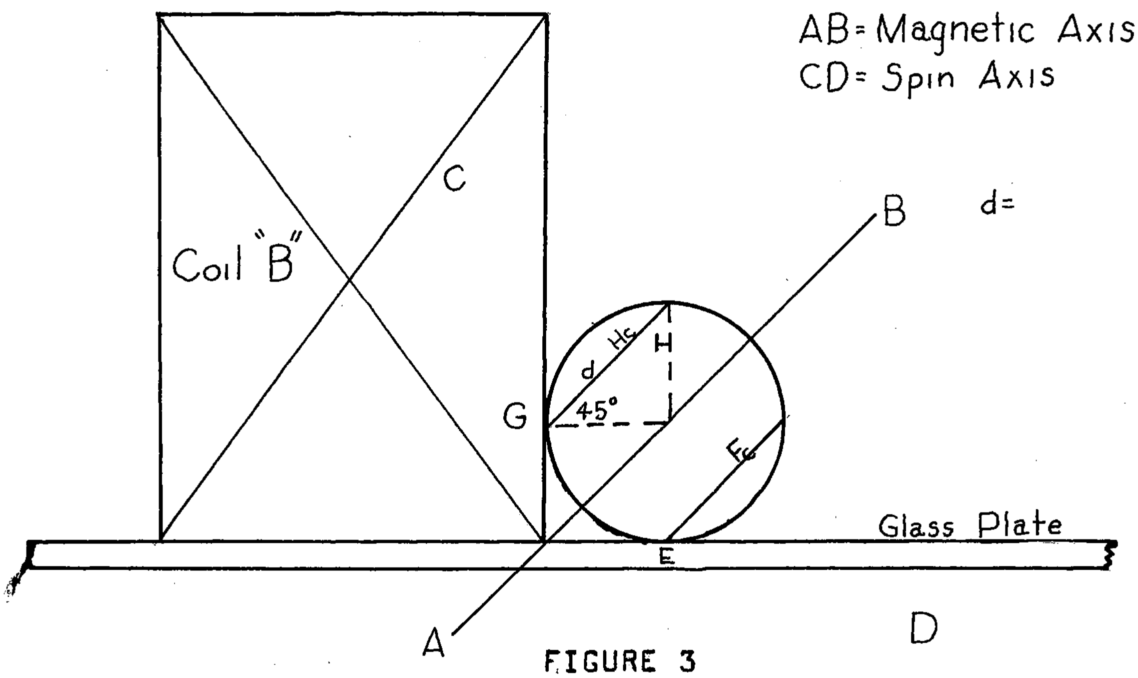


FIGURE 3

To determine the rate at which the balls were rotating and the circumference or circumferences on which they were rotating the following calculations were evolved.

Rate of Rotation on H_c

Coil Circ. = 17.7"

$\frac{3"}{32}$ Balls $d = \frac{.047}{.707} = .066\pi$

$= .207" = H_c$

$\frac{42}{60}$ rpm $= .7$ rps $\times 17.7$

$= \frac{12.39}{.207} = 59.4$ rps

$\frac{1"}{8}$ Balls $d = \frac{.0625}{.707} = .0885\pi$

$= .277" = H_c$

$\frac{57}{60}$ rpm $= .95$ rps $\times 17.7$

$\frac{6.7}{.277} = 60.3$ rps

Rate of Rotation on F_c

$d = .066"$

$F_c = .207"$

$C_c = 17.7 - .094 = 17.6"$

$.7 \times 17.6 = \frac{12.3}{.207} = 59.6$ rps

$d = .0885"$

$F_c = .277"$

$C_c = 17.3"$

$.95 \times 17.3 = \frac{64.3}{.277} = 59.5$ rps

Rate of Rotation on H_c

$\frac{1}{4}$" Balls $d = \frac{.125}{.707} = .177$"

$= .56 = H_c$

$\frac{120 \text{ rpm}}{60} = 2 \text{ rps} \times 17.7$

$= \frac{35.4}{.56} = 63 \text{ rps}$

Rate of Rotation on F_c

$d = .177$"

$F_c = .56$"

$C_c = 16.8$"

$2 \times 16.8 = \frac{33.6}{.56} = 60 \text{ rps}$

c. The third method consisted of wiring the coils in parallel circuits, and regulating the current in each coil by means of two rheostats so that the coils would produce equal fields. It could then be shown by vectors that the resultant field would be at 45 degrees. See Figure 5.

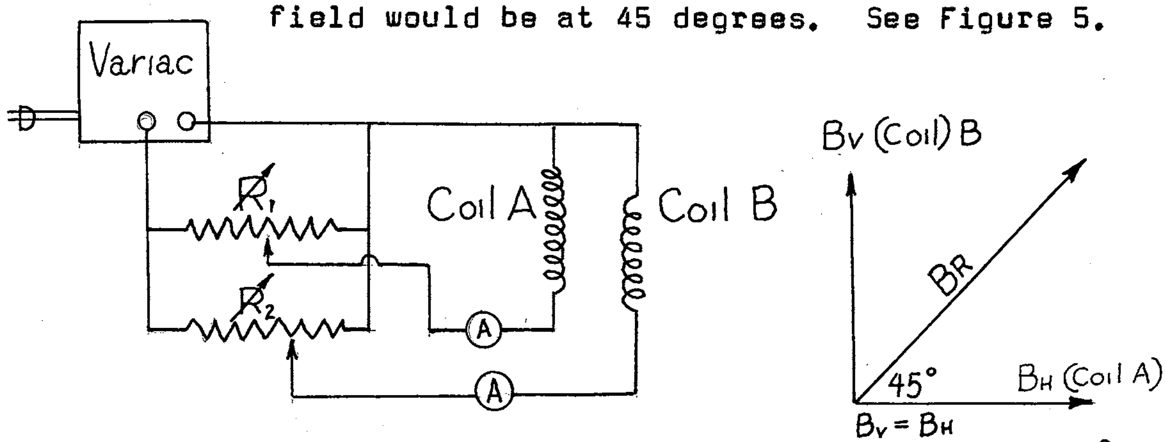


FIGURE 5

As further verification, a 1/4" ball was blackened by dipping in a concentrated nitric acid solution, magnetized, and its poles marked with gold colored paint spots. The ball was then made to roll around the coil with standard current applied, while the marked poles were observed. Since tha ball rotated quite rapidly, it was necessary to employ the use of a stroboscope to "stop it" for visual inspection. It was observed that the poles of the magnetized ball rotated in a plane at about 45 degrees above the horizontal, thus quite definitely establishing the field direction, magnetic axis of the ball, and spin axis of the ball normal to the magnetic axis of the ball.

Results of Observations:

Using the 3/32" balls, as the current and magnetic field intensity were increased, the balls quivered and rolled around in a disorganized manner at first and then started to revolve in single file around the inner perimeter of Coil B. Current changes between limits of 0.5 amps and 5.0 amps had no affect on the velocity of revolution. At currents below 0.5 amps the balls bumped into each other and stopped. The widely spaced balls gradually caught up to each other until the distances between the balls were uniform. This distance was proportional to the current intensity for balls of one size. Larger balls maintained longer spacing for the same current values. Using a stop watch, the balls were timed for one minute to determine their angular velocity around their path.

	Current	RPM Around Coil	Minimum Current
	3	42.25	0.5
	3	41.75	0.5
	3	42	0.5
Average	3	42	0.5

Using 1/8" balls, the same results were obtained except that the balls will not orbit themselves but had to be started with a manual force. The speed of revolution was also different, as shown on the following page.

	Current	RPM Around Coil	Minimum Current
	3	57	0.75
	3	57	0.25
	3	57	0.5
	3	57	0.5
Average	3	57	0.5

The 1/4" balls also had to be started manually. Counts on their speed produced the following data:

	Current	RPM Around Coil	Minimum Current
	3	119	2.0
	3	121	1.8
	3	120	1.8
Average	3	120	1.8

The 3/8" balls failed to orbit. Only a slight quivering or vibration was observed and no amount of effort could induce them to start rotating.

Results with coils wired to produce aiding fields were unsatisfactory because in actuality, the fields at the point of rotation of the balls are opposing even though the fields as a whole are aiding. Thus, magnetic induction of the balls was slight due to decreased field intensity, and produced insufficient torque to overcome the inertia and friction of the balls, so rotation could not be induced.

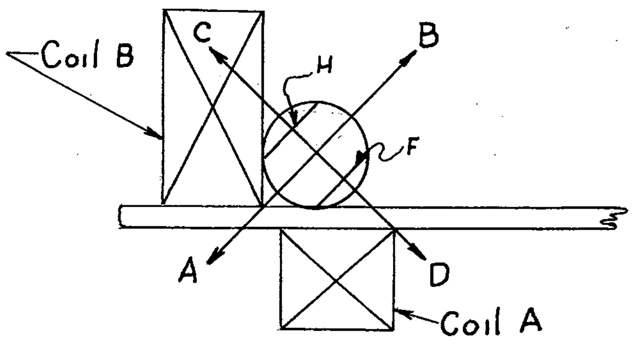
Interpretation of Results:

All available data indicated that the "race track" phenomenen here demonstrated is a variation of the simple synchronous electric motor principle, that is, if a magnet capable of rotating is placed in an alternating magnetic field with its magnetic axis at right angles to the field, a torque is produced which causes rotation the rate of which is equal to the rate of rotation or alternations of the field.

Trial and error experimentation with various coil arrangements and electrical hook-ups proved the above arrangement with fields opposing the most satisfactory for demonstrating this phenomenon. Actually, with this hook up, application of the right hand rule shows that the fields are additive at the lower edge of Coil B where the balls revolve.

Perhaps the best explanation of how and why the balls operate is this hypothetical example. A magnetized ball with a magnetic field and axis much like the earth's is placed on a horizontal glass plate with its magnetic axis oriented by chance in any direction with respect to the horizontal plate. Suppose the ball is then subjected to a uniform vertical alternating magnetic field. If the magnetic axis is in any position except vertical, a varying torque will be produced. The ball will start to accelerate, rolling (end over end, so to speak) on its vertical axis. It will continue to accelerate until it is spinning at synchronous speed (one-half rotation for each alternation of the field), and is producing zero torque when the final velocity is reached. This acceleration to synchronism occurs, apparently, even in the face of friction losses. There is one limiting factor, however, which is the size of the balls. As the size of the balls increases, the moment of inertia increases at a rate greater than that of the torque produced. In this event, the balls merely vibrate in the field. This was the case with the 3/8" balls which were used.

This simple hypothetical case explains how rotation may be induced, but does not fully explain why and how the balls circle the inner circumference of the coil. The diagram in Figure 6 is instrumental to this explanation.



A-B - Magnetic axis of ball

C-D - Spin axis

FIGURE 6

When the magnetized balls are placed in Coil B, their various magnetic axes have no particular orientation. When the current is turned on, the balls are immediately subjected to two magnetic forces. In one case, the imaginary flux lines, acting like stretched rubber bands, draw the balls to the inner circumference of the coil. At the same time, the magnetic poles of the balls are subject to the uniform alternating magnetic field produced by the coils and inclined at a 45 degree angle as proved by Procedures 9a, 9b, and 9c in this report. This field will apply a torque to the poles of the balls and will line up the magnetic axes of the balls as AB in Figure 6. The fact that the magnetic axes of the balls do line up parallel to AB and that the spin axes are normal to AB, e.i., as CD in Figure 6, was shown by Procedures 9a, 9b, and 9c. It was first hypothesized that the balls accelerate to synchronism, that is, sixty rotations per second to correspond with the 60 cycle current which causes 120 field reversals per second. This hypothesis was verified by Figure 3 and the calculations shown on that page. It was found, as shown by Figure 3, that the ball rotates on two shortened circumferences, F which contacts the glass plate at point E, and H, which contacts Coil B at G. By computation, the following figures were determined which definitely indicate that the balls are traveling or rotating at synchronous speed:

	Circumference F	Circumference H
3/32" balls	59.4 rps	59.4 rps
1/8" balls	59.9 rps	60.3 rps
1/4" balls	60.0 rps	63.0 rps

The distance traveled around Coil B is slightly greater for circumference H than for circumference F; therefore, there must be slippage at either point G or point E. The question arose, on which circumference, F or H, is the ball rotating and on which does slippage occur? This called for a re-evaluation of the forces involved although the rotational velocities of either circumference is highly significant, as the figures show.

The coefficient of friction between the balls and the coil at the point G is 0.56 and between the balls and the glass plate at point E is 0.2. In the case of the 3/32" balls, the force down, mg, is 5.4 dynes, and the centrifugal force horizontally, F_c, is 6.2 dynes. Electromagnetic forces in each case are equal since the resultant field is at 45 degrees. A horizontal force of 6.2 dynes and a horizontal coefficient of friction of 0.56 being greater than the downward force of 5.4 dynes and coefficient of 0.2 indicate that the true rotation occured about circumference H and Coil B at point G, and that slippage occurred between the ball and the glass plate. A similar situation occurs with the larger balls so it seems evident that the true rotation takes place between the ball and the coil, although the calculations of the velocities of the F circumference more nearly approach the 60 rps speed. Both sets of calculations, however, lie well within the error of experimentation.

One further aspect of this phenomenon requires explanation: that is, the spacing the balls acquire as they followed each other around the coil. When started, the balls were irregularly spaced around the coil. As they circled the coil they tended to draw closer and closer together until a certain even or uniform spacing was attained which they then maintained indefinitely. The diagram in Figure 7 illustrates the cause of this peculiarity.

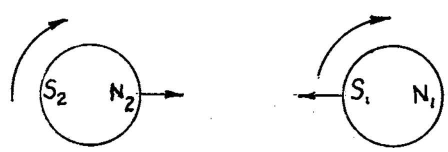


FIGURE 7

All balls running around the coil maintain parallel magnetic axes. By analyzing the varying forces operating between rotating synchronized balls, it is found that the force between them varies between plus and minus values, but that there is a net force of attraction over the whole cycle. In Figure 7 it is seen that the total attractive force between S_1 N_2 and S_2 N_1 is greater than the total repulsion between N_2 N_1 and S_2 S_1 because the attractive forces (N_2 S_1 in this case) are always closest and these forces vary inversely as the square of the distance. Thus, the balls tend to slip and draw close to each other.

Since, however, they do not come together, some other force must hold them apart. This force is, of course, the magnetic repulsion of the balls. This was illustrated by the fact that if two magnetized balls are stuck together and placed in the coil, a sufficient current strength caused them to repel and separate.

The circling balls would then, if too far apart, draw closer together until a balance is reached between attractive forces and repulsive forces. If placed too close together, they would separate to the same spacing.

Final spacing was found to vary directly as the field intensity or current strength, and the size of the ball.

INVESTIGATION III

Problem: To determine the effects of an alternating magnetic field on unmagnetized steel spheres.

Apparatus: Coil A, Coil B, glass plate, variac, voltmeter ammeter, steel balls 1/8" diameter, two sheets of flat rubber with hexagonal openings cut and notched as in Figure 8. These were made from an ordinary kitchen sink mat.

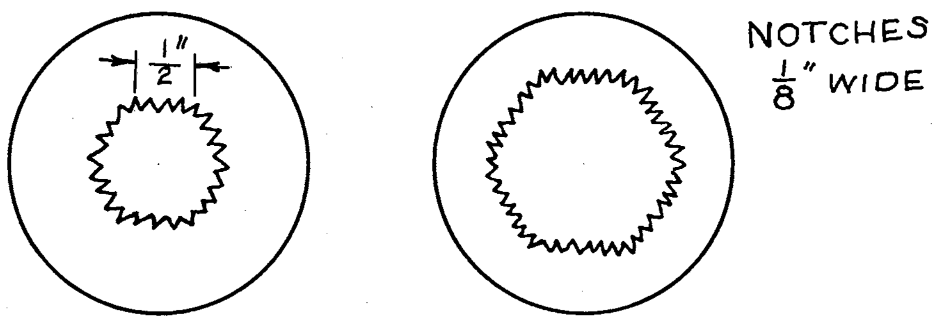


FIGURE 8

Procedure:

Only one coil was used first, placed with the smaller rubber sheet in its center. A number of 1/8" spheres were placed in the hexagonal opening. When 5 amperes of 60 cycle alternating current were flowing in the coil, the spheres began to arrange themselves in a definite orientation resembling a crystal structure. The proper number of balls were then added until a perfectly symmetrical pattern was obtained. This occured with 61 balls, which arranged themselves in four shells around a single center ball, the first shell containing 6 balls, the second 12, the third 18, and the fourth 24, as shown in Figure 9.

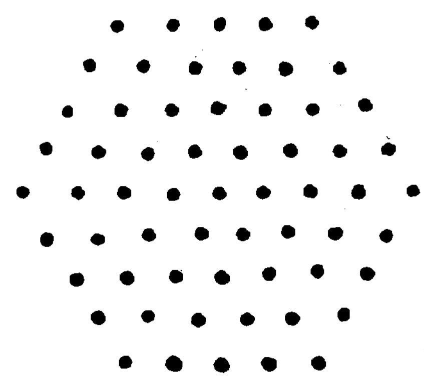


FIGURE 9

The larger hexagon was then placed in the coil and the crystal arrangement again formed in the same manner except that there were 7 shells about the center ball, containing a total of 169 balls. This formation was not quite as uniform and symmetrical as the first, as the balls crowded towards the outside, thus causing the outer shells to be crowded closer together than the inner shells.

The preceding procedure was then followed using both coils hooked in series, the large one above the small one as in Figure 2, their fields opposing. No appreciable change in the results were observed. With the fields hooked in series aiding, however, it was thought that perhaps the rubber retaining sheet was not needed. With the sheet removed, the balls tended to form a circular pattern within the area of the smaller coil. The shells were again not as pronounced as when using the retaining rubber sheets. Negative results were obtained with no rubber retaining sheet and fields hooked in opposition.

Interpretation of Results:

The orderly arrangement of the balls under these conditions can be explained in terms of magnetic induction due to the alternating magnetic field. When the field was in one direction for one-half cycle, all balls were magnetized alike, with all N poles in one direction and S poles in the other. This caused each to repel its neighbor. Quantitatively then, since all balls were the same size, had the same permeability, and in an essentially uniform field, each were magnetized the same and so would repel all others with the same mutual force. Thus, each ball tried to move as far away from its neighbor as possible, and all, in doing so, formed the uniform pattern observed.

When the fields were connected in series aiding, the balls formed a pattern within the area of the smaller coil without the use of the rubber sheet. This can be explained by first analyzing the shape of the field, as shown in Figure 10.

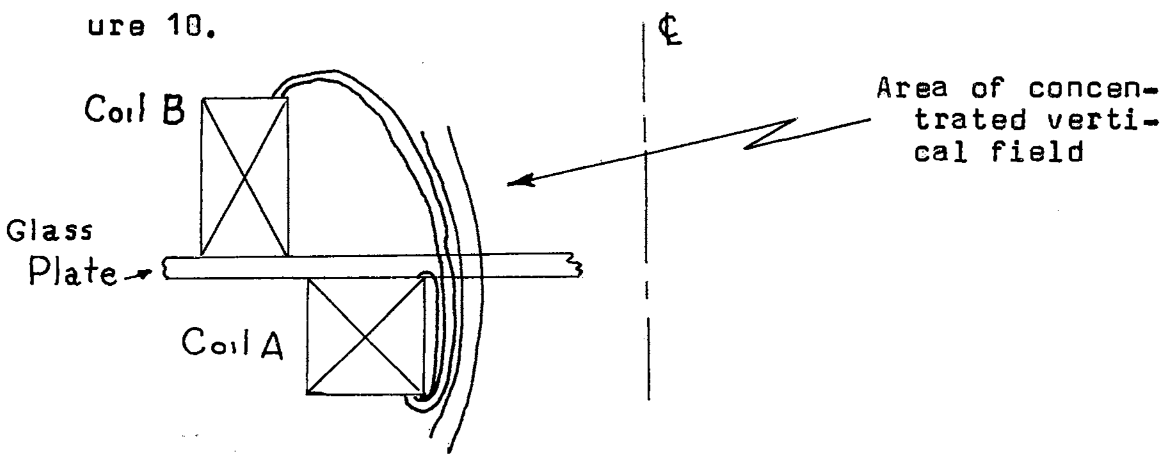


FIGURE 10

There being few vertical lines of force outside the area formed by the smaller coil, the balls, being magnetized by induction, would be attracted by the field and hence stay within the area described. Again they tend to form a pattern as previously explained.

With the fields in opposition, the field of force draws them out to the large coil because the lines are no longer vertical and concentrated within the small coil area.

INVESTIGATION IV

Problem: To determine the effects of a strong alternating magnetic field on unmagnetized steel spheres.

Apparatus: Coil A, Coil B, variac, voltmeter, ammeter, steel balls of diameters 0.170", 0.125", 0.093", and 0.033".

Procedure:

It was noticed in Investigation III that under higher currents and thus stronger magnetic fields, the 0.125" spheres began to act strangely which prompted the pursuit of this course of investigation.

With one coil (either A or B) connected and carrying a current of about 7 amperes the spheres began to pile up, one on top of another while still being retained within the rubber sheet used in Investigation III. Upon a still further increase in current, the balls jumped up and over the rubber and went outward to the coil. The rubber sheet was then removed for this Investigation.

About 60 to 80 balls were placed within the coil area at random and the current turned on and slowly increased. The balls were drawn to the outside where they began to line up in rows. At about 10 amperes the rows began to raise until a current of 12 amperes was reached, whereupon the ball strings were in vertical positions, one ball on top of another in columns up the inside surface of the coil, and spaced quite evenly around the circumference.

This was repeated except that this time the current was turned on quite suddenly instead of slowly. In a fraction of a second the balls raced to the outside and again lined up in uniformly spaced vertical columns up the inside surface of the coil.

This procedure was repeated several times and counts were taken on the number of columns formed. Also, different sizes of balls were used and several counts taken on the number of rows each size formed. These results are shown tabulated in Figure 11.

Ball Dia. in Inches	Number of Columns Formed				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
0.170	21	22	21	20	21
0.125	29	28	27	28	28
0.093	37	36	35	35	36
0.033	62	61	67	65	63

FIGURE 11

Interpretation of Results:

Under higher currents and the resulting intense magnetic field, the spheres were magnetized more intensely by induction. At any one instant two adjacent balls were magnetized with N poles on top and S poles on the bottom or vice versa thus becoming two small magnets as shown in Figure 12.

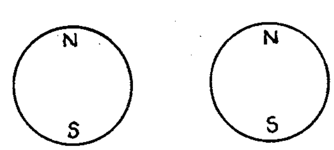


FIGURE 12

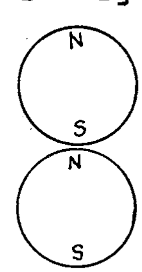


FIGURE 13

When the force of attraction between the opposite poles became strong enough to overcome the force lining the ball in the field, one ball was rotated 180 degrees and attracted to its neighbor. The force of attraction was strong enough to overcome the force of gravity and the ball jumped on top of its neighbor thus matching opposite poles as shown in Figure 13.

When the rubber retaining sheet was removed the balls were drawn outward toward the more intense magnetic field until they encountered the coil and were stopped. Here the field was so strong that more balls jumped on top of the two as explained in the preceding paragraph, until a complete string or column was formed up the inside of the coil and held in position by the field of force.

Adjacent columns repelled each other with a definite force determined by the cross sectional area of the balls. Each column may be considered at any instant to be a permanent magnet with N poles at the top and S poles at the bottom, since the direction of the field producing the induction is the same in both columns. The columns then spaced themselves in a definite number of rows around the coil as is shown in Figure 11. The number of rows formed is an inverse function of the square root of the area of cross section of the balls. This can be shown mathematically in the following manner:

Total flux of electromagnetic induction ϕ is given by

$$\phi = BA$$

or, the amount of induction in the balls is a function of the area of cross section, A. The force of repulsion of the two columns is $$F = \frac{m_1 m_2}{\mu S^2}$$

Since the strength of the magnet produced depends on the flux density Ø, it can be stated that m is a function of A. So,

$$S^2 \propto \frac{A}{F} \quad \text{and} \quad S \propto \sqrt{A}$$

where s is the distance of separation of the columns. The total number of columns around the coil N, is inversely proportional to s, so $$N \propto \frac{1}{\sqrt{A}} \text{ , or,}$$

$$\frac{N_1}{N_2} = \frac{\sqrt{A_2}}{\sqrt{A_1}} = \frac{\sqrt{\pi r_2^2}}{\sqrt{\pi r_1^2}} = \frac{r_2\sqrt{\pi}}{r_1\sqrt{\pi}} = \frac{\frac{d_2}{2}}{\frac{d_1}{2}} = \frac{d_2}{d_1}$$

Substituting values from Figure 11:

$\frac{21}{28} = \frac{.125}{.170}$ Cross-multiplying yields 3.57 3.50

and $\frac{28}{36} = \frac{.093}{.125}$ yields 3.50 3.34

which are within the limits of experimentation.

INVESTIGATION V

Problem: To determine the effects of a uniform vertical electromagnetic field on small steel magnetized and unmagnetized balls of 0.007" diameter which are floating on water in a polyethelyne container placed centrally in the field.

Apparatus: Coil A, and Coil B hooked as in Investigation IV; variac; ammeter; permanent magnet; plastic spoon.

Procedure:

1. The coils were arranged and spaced as in Figure 14, and wired to produce uniform vertical fields in series aiding. The bowl with 1/2" of water in it was placed in this field as shown also in Figure 14.

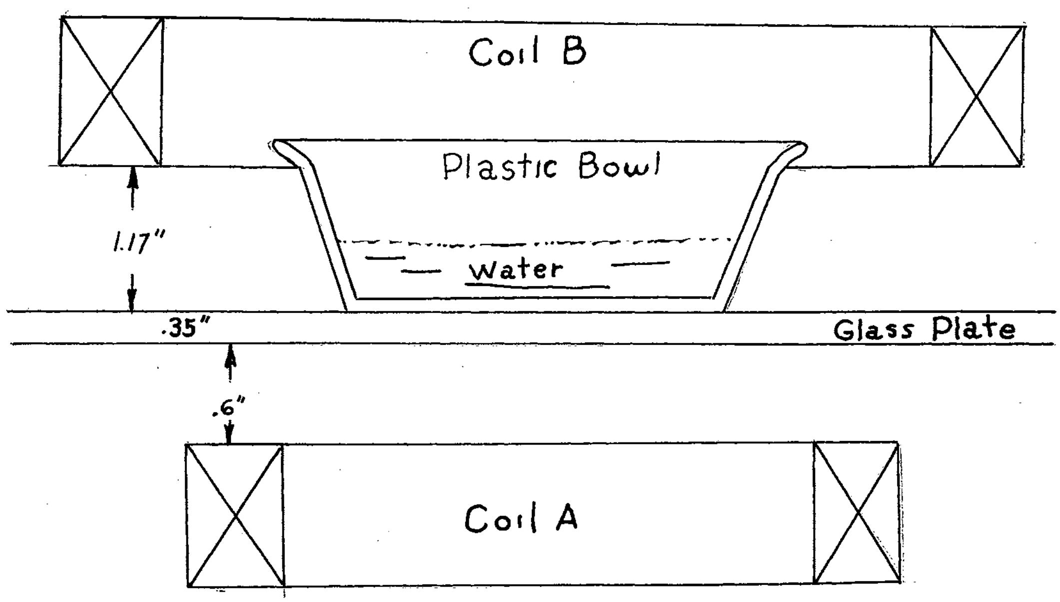


FIGURE 14

Using unmagnetized steel balls of 0.007" diameter (larger ones could not be made to float) and with a current of three amps applied to the coils, the balls were laid on the surface of the water with small forceps, one at a time. Resulting arrangements were recorded.

2. To build a floating raft of many balls, the unmagnetized balls were placed in a plastic spoon. With a field current of three amperes, the spoon was lowered slopingly to a point near the water surface. The balls magnetized by induction, activated by the magnetic field hopped off and floated individually and then moved towards each other, down the depression in the water surface caused by their weight and being supported by the surface tension of the water. Using shot rafts of two different sizes, one size being about 1/4" in diameter and the other about 1/2" in diameter, the current was then varied between 0 and 10 amps and the results were recorded.

3. Active floated formations were produced by depositing magnetized balls on the water surface by the process described in Procedure 2 previously. Results at various currents were recorded.

Results:

1. As the unmagnetized balls were floated one at a time, as in Procedure 2, they tended to float together in the same depression of the water surface. On the other hand, the vertical magnetic field magnetized them and caused them to hold each other apart by magnetic repulsion, hence, the distances which they maintained from each other varies

as the strength of the field. Stable formations were observed repeatedly, at every trial, as shown in Figure 15, for the respective number of balls floated in each case. No other formation could be induced permanently, by any manual manipulation.

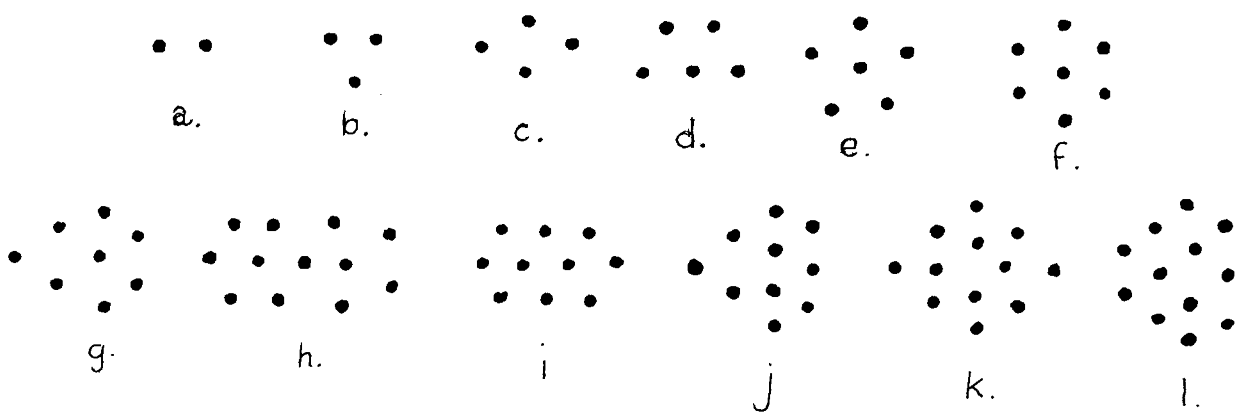


FIGURE 15

2. Shot rafts of both sizes (1/2" and 1/4" diameters) at zero or very low currents or field strength appeared much the same, tightly packed in a single layer, roughly circular, and depressed in the center like a shallow cone. However, as the field current was increased, the two shot raft sizes exhibited different behavior patterns. Because the rafts were in a plane normal to the field, the field caused magnetic repulsion. As the current increased, this repulsion in the case of the smaller rafts caused a symmetrical many-rayed star to appear as shown in Figure 16. At lower currents the center was still solid. At increased currents, the separation increased until a field of individual balls spaced symmetrically in concentric circles formed. If the current was lowered, the

balls collected into the original tightly packed formation.

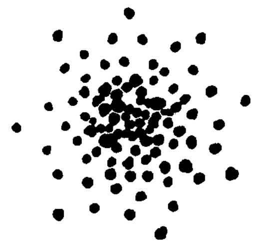


FIGURE 16

In the case of the larger rafts, a very different behavior developed. With the gradual increase of the current, the balls remained tightly packed but began to bulge downward more and more, forming a deep dry pocket. As the pocked bulged downward deeper and deeper, the upper edges of the raft drew closer and closer together until they finally met, entrapping a bubble of air. The then spherical mass of balls, entrapped bubble, and all, sank to the bottom. See Figure 17.

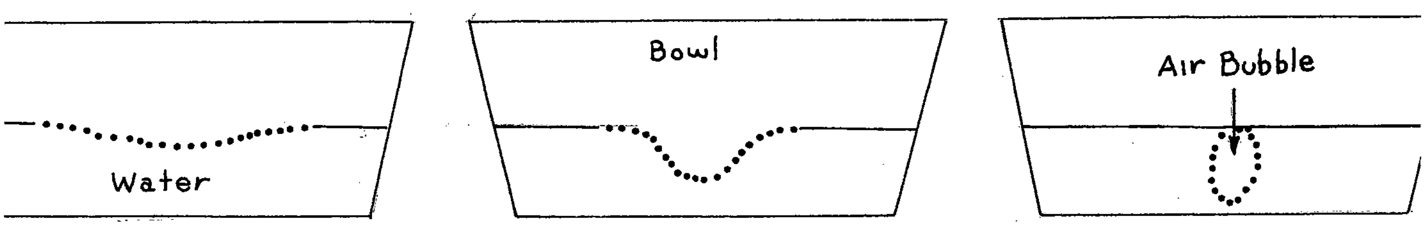


FIGURE 17

3. When magnetized balls were deposited on the water surface, an almost endless variety of formations and movements resulted. Sometimes one, two, or several balls aggregated and whirled rapidly in a fixed position. Often, lifelike organisms formed and swam around. These had a "backbone" of several short ball chains, with gaps between them, and

had many "legs" or outriders. The whole structure swam around like an animated centipede. At other times, fairly stable organisms (See Figure 18) formed and "swam" around the magnetic axis of the coils in circles roughly 2 inches in diameter.

FIGURE 18

Interpretation of Results:

Results of Part 1 indicated that the equilateral triangle is the basic stable formation from which the more complex formations were constructed. This seemed to be the most logical explanation, since the masses of the balls were constant, and the magnetic repulsion of the balls was constant, it followed that the distance between balls must be constant. The equilateral triangle is the only formation that can meet all these requirements.

The many rayed star formed in Part 2 when the small (1/4" diameter) unmagnetized shot raft was subjected to increasing field current is more easily explained. The induced magnetism increases with the field current causing increasing repulsion between the balls, thus producing greater and greater separation. This phenomenon might be used as a simplified model of the "expanding universe" theory.

In the case of the larger sinking shot raft, other forces were acting. In Figure 18, the larger raft, due to increased weight, caused a deeper depression on the water surface. Thus the repulsive force of the balls, due to increased field strength, was unable to produce horizontal separation, as was the case with the smaller rafts, because radial horizontal movement of the balls was prevented by a combination of forces greater than the spreading repulsive force of the magnetized balls. The forces opposing lateral movement were gravity and inertia which were also acting on the smaller rafts, and surface tension, which, acting normal to the surface, would have a much greater component due to the increased depression of the surface. Since lateral radial movement was thus inhibited, the only way the balls could move, as a result of repulsive forces, was downward. As the balls near the center of the raft were forced down, the angle of the depression increased, thus the repulsive force of the balls was acting more vertically and less horizontally. The forces opposing radial movement would therefore be correspondingly greater and force the edges of the raft closer and closer together as the center descended, until finally they met, encompassing an air bubble and sinking. This is shown in Figure 19.

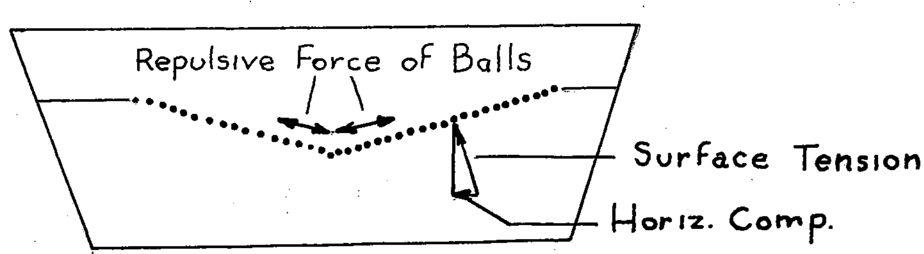


FIGURE 19

The dynamic results produced when magnetized balls were floated in the field were beyond the abilities of the experimenter to explain in most cases. Some of the forces involved were explainable, however. Chaining was recognized as the simple tendency of the unlike poles of the balls to attract and attach. Observation of the reacting balls through a microscope showed them to be vibrating and rotating horizontally, but not vertically as synchronous motors. This vibration and oscillation set up easily discernable, strong standing waves which undoubtedly affect the ball movements in some way. As further proof of this, it was recognized that vertical rotation would wet the balls and cause them to sink. Sinking did not occur. Thus, the movements of the active floaters were produced by vibration or oscillation as the primary motivating principle. The balls reacted magnetically with each other, their interaction with the water surface undoubtedly produced forces, and the standing waves effected movements in some manner. A combination of all of these forces and perhaps some others not mentioned contributed to the production of the most erratic movements observed.

Various other odd formations were observed which strongly resembled general shapes of galactic arrangements which astronomers tell us exist. One such was a formation consisting of a center bar and a tail at right angles at either end which imparted to the whole, a slow rotary motion. Another was a circular monoplaner formation in which the constituent particles were in constant vibratory movement.

Other formations under certain circumstances highly resembled living bacteria in the process of bacterial chaining, and still others resembled one celled animals such as exist in water.

INVESTIGATION VI

Problem: To charge a polystyrene plastic bowl with static electricity and observe the effects of such a charge on small steel spheres placed in the bowl.

Apparatus: Polystyrene plastic, flat bottom bowl approximately 3-1/2" in diameter; steel spheroids 0.007" diameter; silk cloth.

Procedure:

For this Investigation, atmospheric conditions had to be such that they were conducive to bodies acquiring and holding static electric charges. The primary procedure followed was quite simple. A few hundred of the steel balls were placed in the bowl. The bowl was then rubbed briskly on the bottom with the silk cloth, thus putting a static electric charge on the bowl. When the cloth was moved away, the spheres began to move about in a most confusing and erratic manner. The most obvious movement that was first noticed was a rapid transfer of the balls up the side of the bowl to points where the investigator's hand or fingers were contacting the bowl. This indicated an attraction between the balls and the fingers which then prompted the touching of the bottom of the bowl. The balls were attracted again and would collect and stick to a small area directly above the point where the finger touched. The finger was then brought up, over the side, and approached the bottom of the container from the inside. The balls were immediately repelled and moved away. The bottom was then actually touched and rubbed in a small area with the finger, and the balls then failed to collect at that area, but instead, completely avoided it.

This strong attraction of the balls for the hand outside the bowl was quite evident in another manner. When the bowl was rubbed vigorously and the cloth drawn away very rapidly, many of the balls actually jumped completely out of the bowl and came to rest on top of the hand which was holding the bowl.

At this point, the charge on the bowl was tested with an electroscope. The electroscope was first charged negatively by conduction with a rubber rod rubbed on fur. The bowl was then brought near the electroscope and the leaves diverged indicating the presence of a negative charge on the bowl. This evidence later seemed inconclusive because of other observations.

Other interesting phenomena were observed by tilting the bowl, after being charged quite strongly. As the bowl was tilted to about 45 degrees, the spheres rolled down and many of them massed together; but, many sprang back up the inclined surface to distribute themselves at random over much of the bottom surface. The bowl was then rotated a little bit. Some of the balls rolled down the edge of the mass collected at the bottom; but others, defying gravity, left the edge and moved upward away from the edge to roll across and among the distributed balls and came to rest somewhere near the opposite edge of the bowl.

It was suspected that the bowl was being electrified in small localized areas at times. To test this, the silk was wrapped over one finger and then the bowl was rubbed briskly in one spot on its side. As the cloth was drawn away, some balls were immediately attracted to that spot and they jumped up to it and stuck in that area. This was repeated at a spot about 2 inches away from the first and again in a third spot about 4 inches away. In each case, the result was the formation of a group of balls on those small areas.

When a medium charge was put on the bowl in some instances, the balls would act in such a manner as to remind one of certain actions of pith balls in ordinary electrostatic demonstrations. Two masses of balls formed in small local areas about 1/2" apart. A steady stream of balls was noticed going back and forth between the two masses. A ball would touch one mass, reverse its direction and go back to the other mass. Upon contacting it, the ball would again reverse and repeat the operation many times. This is very similar to the action of a pith ball bouncing back and forth between a charged rod and its ring stand support.

Under ideal atmospheric conditions (low humidity) the balls could be made to electrify themselves by simply shaking them around the bottom of the bowl. Friction between the ball and the dielectric charges each with opposite polarity. This was accomplished for a few minutes at one time, but in general, the bowl had to be electrified by external rubbing.

In addition to specific observations heretofore described, many more strange and thought provoking phenomena were observed which can hardly be described in words. These fascinating antics have to be seen to be really appreciated.

Interpretation of Results:

All of the observed actions were, of course, based upon the laws of attraction and repulsion of unlike and like electric charges. The interpretation of these laws and application to specific movement was not so easily accomplished. It is quite obvious that as the bowl was being given a general negative charge, the balls were in general acquiring a positive charge, a fact which was tested with a rubber rod charged negatively; however, this simple observation does not at all suffice to explain everything.

The extreme attraction between the balls and the hand holding the bowl can be explained in the following manner: It seems plausible to believe that although the bowl was charged negatively, some of the balls failed to acquire the positive charge mentioned, so would strongly repel the bowl. The hand, being of opposite charge or even neutral, would attract them, and these combined forces, acting on the very small mass of the balls would cause them to move quite rapidly, as was observed. Always this attraction for the hand or finger outside the bowl was evident. In noting this and other similar actions, the investigator was convinced that it was possible to electrify the bowl only in small localized areas. This was only theorized and certainly not proved conclusively. It was realized that a much deeper knowledge and understanding in the field of plastics was necessary to prove or disprove this - an understanding which was lacking in the investigator.

The analogy related to pith balls previously described can be explained much on the same terms as are the pith balls. A ball became charged negatively, by contact, and thus repelled the group of balls which charged it. The ball then moved across an area to another group and by contact again, gave up some electrons to this group which in turn would repel it, causing it to move back to the first group and repeat the process again and again.

Much was left unexplained at this point, partly due to lack of equipment and lack of time to pursue it further.

INVESTIGATION VII

Problem: To observe the effects of alternating magnetic fields on very small magnetized and unmagnetized steel balls.

Apparatus: Coil A, Coil B arranged as in Investigation V, with spacers; small plastic bowl with flat bottom; steel spheroids with 0.007" and 0.016" diameters; stroboscope; magnifier.

Procedure:

A few hundred balls 0.016" in diameter were put in the bowl and magnetized by placing the bowl on a strong permanent magnet for several minutes. The bowl was then placed inside the top coil and resting on the glass plate. The coils were hooked in series, fields aiding, to produce a vertical field through the bowl. As the current was turned on and raised to two amperes, some of the balls began to shuffle and vibrate. As the current was increased slowly up to about four amperes, nearly all the balls were in action. Some were rotating in one spot, others were whirling about in small circles, while most were rolling wildly about the bottom of the bowl in quite erratic patterns and motions. They moved in straight lines for a distance, then in curved paths of varying radii. The whole group of balls was one swirling mass of movement.

As the current was increased still further, the activity slowed and the balls started to pile on top of each other, forming many small protrusions from the bottom of the bowl which resembled trees in a forest.

The current was then reduced to a low value of two amps or less and short chains of balls began to form. These chains were about 1/2" to 3/4" long and were very irregular in shape. They wiggled about, looping first one direction, then another resembling chains of living bacteria.

At this point, the balls had lost much of their magnetism due to the alternating field present and had to be remagnetized. After remagnetizing, they again performed in the same manner and this was repeated as often as was desired.

The "forest" before mentioned was then repeated using several thousand unmagnetized balls 0.007" in diameter. These gave striking resemblance to a pine tree forest as they piled up broad at the base and tapered up to a point at the top. As the current was increased to 10 or 12 amperes, the "trees" grew larger and moved outward until they were stopped by the edge of the bowl and collected there maintaining, however, appreciable distances between each one and its neighbors.

A couple hundred 0.016" balls were then plated with copper in an attempt to set more of them into action. They were washed in dilute nitric acid and then stirred in copper sulfate solution for a few minutes. The copper displaced the iron and the balls became covered with a heavy, dull copper plating. They were laid out to dry and then polished by rubbing them between the thumb and a plastic bowl. These balls did seem to perform better after being magnetized and placed in a field before described.

About 10 of these balls were placed in the bowl in an attempt to analyze their movements more closely. After being set into motion, they were studied with a magnifying glass. As far as could be determined, in all their haphazard rolling about, they never bumped into another rolling ball but did collide with an occasional stationary ball, a few of which were always present. More balls were added and still they seemed to roll in and out among and around the other balls, but probably collisions did occur. Attempts to "stop" the balls with the stroboscope in order to verify this proved unsatisfactory.

Interpretation of Results:

The observed erratic movements of the balls can be understood on the basis of interaction of magnetic fields, thus producing varying torques, attraction and repulsion of magnetic poles, changing friction, and probably many other conditions. The principal reason for the balls rolling at all is the same as that explained in Investigation II; namely, each ball was acting like a small induction motor rotor. Since it is magnetized, it is attempting to rotate at synchronous speed with the alternating field. There were many deflecting influences in this investigation which prevented the balls from circling as they did in the "race track".

If a rolling ball is acted upon by deflecting influences, such as by crossing a field of changing density, or suffering a change of friction with the bowl, or in starting to climb the slope of the bowl sides, forces between itself and the bowl induce gyroscopic action. Precession of the axis will cause larger and smaller contact circles against the bowl, and so the linear speed and direction of motion will change. A ball may come into the field of force of another ball and the resulting attractive or repulsive forces contribute to change its speed and direction. Hence, the ball would move in a very erratic path.

The "bacterial" chains took place when the balls had lost much of their magnetism. As long as they are strongly magnetized, they tend to rotate and repel others; but, as reduced activity occurred under reduced current, balls are rolled to positions where the south pole of a ball may catch onto the north pole of another and a chain would begin to form. When several were linked pole to pole, the whole group acted as one flexible magnet, still retaining enough magnetism to be acted upon weakly by the applied field and were caused to wiggle and loop one way and another.

When only a few balls were in the bowl, they had a lot of area in which to move around. It seemed probable that their magnetic fields, both permanent and induced, were strong enough to keep them from colliding. As they rotated in synchronism with the field, like poles of adjacent balls should have always been opposite, thus causing them to repel. With several hundred balls in activity, however, the area available for movement of each ball was considerably less so it seems probable that collisions did take place, at least between the faster balls.

The "forest" was a partial ramification of Investigation IV in which the balls piled up in strings, one on top of another. For some reason, the extremely small balls used now were less mobile than the larger ones used then and failed to fly rapidly to the outside. This was probably because of their small mass they did not become such strong magnets due to induction. Under greatly increased currents they did tend to move to the outside of the bowl. More time needs to be spent on this phase of investigation also before complete enlightenment is attained.

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VITA

David Gray Johnson

Candidate for the Degree of

Master of Science

Report: INVESTIGATIONS IN MAGNETOSPHERICS AND ELECTROSPHERICS

Major Field: Natural Science

Biographical:

Personal Data: Born at Biddeford, Maine, May 21, 1927, the son of Herbert F. and Sarah Goldthwaite Johnson.

Education: Attended grade school at Morrill Grade School, Biddeford, Maine; graduated from Manning Junior High School, Ipswich, Massachusetts, June, 1941; graduated from Ipswich High School, Ipswich, Massachusetts, June, 1945; attended Emory and Henry College, Emory, Virginia; attended the University of Virginia, Charlottesville, Virginia; received the Bachelor of Science Degree from Kansas University, January, 1951; did graduate work at Fort Hays State College, Hays, Kansas; completed requirements for the Master of Science Degree in August, 1965.

Experience: Served in the U. S. Naval Air Corps from 1945 to 1947; taught at Sheldon High School, Sheldon, Missouri, from 1953 to 1955; taught at Moran High School, Moran, Kansas, from 1955 to 1956; taught at Frankfort High School, Frankfort, Kansas, from 1956 to 1963; taught at Osborne Rural High School, Osborn, Kansas, from 1963 to 1965.

Professional Organizations: National Education Association, Kansas State Teachers Association, Osborne County Teachers Association, Osborne City Teachers Association, Phi Delta Kappa.