PROPERTIES OF GLASS VOLUMES CONTAINING MERCURY

by

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INTRODUCTION

As early as 1675, it had been observed that mercury in contact with glass in an evacuated chamber produced a glow when agitated (1). In 1705 Hawksbee found that when mercury was placed in a glass container which was then evacuated and sealed, any subsequent mechanical motion of the mercury-glass device produced a visible glow in the gas remaining in the container (2). Little if any further work was done until 1963 when Katsumi Ikenoue and Yoshiaki Sasada published a paper in which they investigated the ultraviolet light emitted from a mercury-glass device when the mercury was mechanically vibrated by heating a small constriction in the apparatus (3).

The mercury-glass devices used in this study were spheres with diameters of approximately 50 mm, and made from Corning pyrex brand glass, code 9741 which transmits light down to 2400 Å efficiently. Finished examples can be seen in Figs. 3, 4, 5, Plate I. The hand blown spheres are attached to a pyrex vacuum system consisting of two forepumps, two mercury diffusion pumps, and an ion pump. Various gases such as helium can be admitted to the system with pressures ranging from 10^{-8} mm Hg to one atmosphere. Commercial grade mercury is placed in side tubes located near the sphere to be filled so that by heating the side tubes gently, mercury can be distilled into the glass sphere, the ion pump being protected from the mercury vapor by a liquid nitrogen trap. All the pertinent facts about the filling of any given glass sphere are recorded since the past history of each device may determine its subsequent behavior.

EXPLANATION OF PLATE I

1. RCA 1P28 Photomultiplier and Circuit
   a. Magnetic shield
   b. High voltage input
   c. Ground post
   d. Output
   e. $\pm$ 20 volt supply terminals for emitter-follower

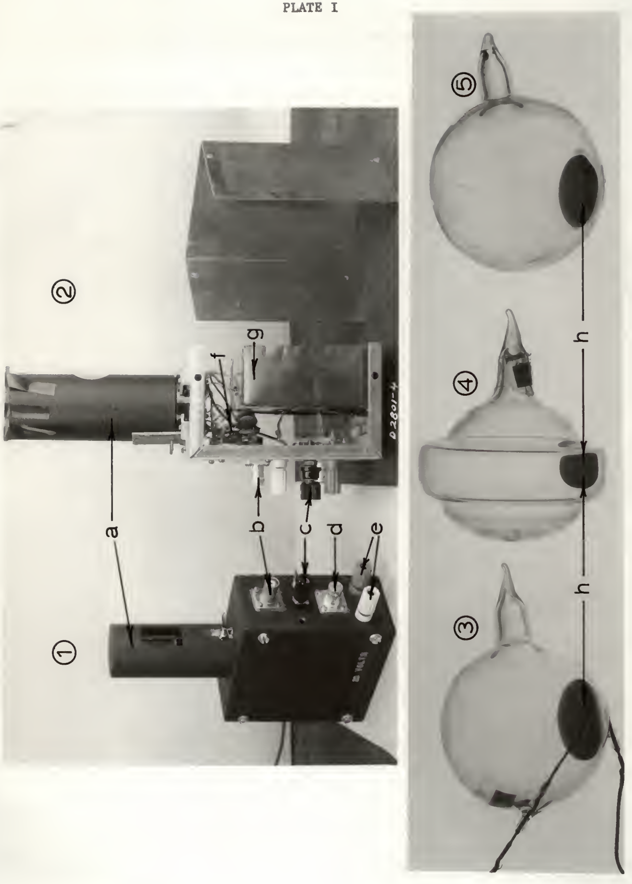
2. RCA 7102 Photomultiplier and Circuit
   f. Dynode chain
   g. Emitter-follower

3. Electrode Ball
   h. Mercury puddle

4. Cylindrical Track Ball

5. Spherical Ball

PLATE I



THE PROBLEM

The problem is to determine the exact nature of the glow effect and to explain its behavior in relation to various conditions of excitation. It is hoped that some practical application may be found for the device and the observed effect.

Some of the visual properties of these rather unique devices which change mechanical energy into light energy will now be enumerated. On gently shaking the sphere, a pale blue-white glow is seen to fill the interior of the ball; on more vigorous agitation, the intensity increases; the metallic clinking of the mercury against the inside surface of the ball can be heard, and small bright pinpoints of light twinkle within the gas in the spheres. The relative intensity of the light depends on the gas pressure within the ball, being weak for low pressures ($\sim 10^{-5}$ mm Hg) and high pressures (>60 mm Hg) with stronger emission at intermediate pressures. The types of glass used seem to have different effects, some glasses being more efficient than others. The rougher the glass surface on which the mercury moves, the larger the light yield. Also, besides the above parameters, the effect seems to be dependent in some measure on the uncertain factor of the past history of the mercury-glass system. It is affected, for example, by the method and care exercised in blowing the spheres, evacuating them, and introducing the mercury. Thus, the explanation of the observed effects for one mercury-glass device may not always suffice for those of another similar sphere. An explanation of the light output mechanism will be discussed in the next section.

THE PULSED NATURE OF THE LIGHT

First, a description of what happens when two different materials are placed in intimate contact will be given. Let the materials have work functions and respectively. Before contact, the electronic energy bands of the materials can be graphically represented as shown in Fig. 1, Plate II. After contact, the Fermi levels of the two materials equalize, and in order to do this a potential barrier is set up between the junction of the two substances. Charges become attracted to either side of this barrier in order to maintain the necessary potential difference; this is shown in Fig. 2, Plate II. For this particular case let material ① be the mercury with a work function of 4.5 ev and material ② be the glass from which it is difficult to remove electrons since it is an insulator. Hence, electrons should be found moving from mercury to glass when the materials are in contact in order to equalize the Fermi levels, as Plate III demonstrates. Since it is difficult to get electrons out of an insulator, it should be equally difficult to get them in. This problem has been recognized before, and a solution was discovered by Tamm and Shockley when the mathematics of semiconductor crystals yielded the possibility of surface states which would be capable of accepting electrons (4). It is assumed that filling of surface states accounts for the effect seen here. It is borne out by the known fact that the surface resistivity of insulators is less than the volume resistivity and in this case by the observation that the inside condition of the glass ball affects the light output behavior. Experiments with the

EXPLANATION OF PLATE II

An Idealized Picture of the Behavior of Two Dissimilar Materials Before and After Contact

Fig. 1. Before contact, materials ① and ② have work functions ϕ_1 and ϕ_2 respectively.

Fig. 2. After contact the Fermi levels of the two materials equalize by forming a contact potential, V, at the interface equal to $\phi_1 - \phi_2 \; /e$ where e is the electronic charge.

PLATE II

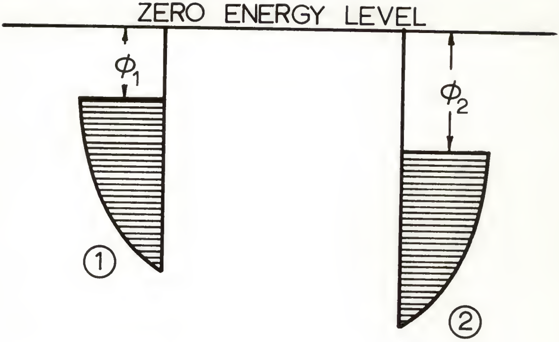


FIG. 1 BEFORE CONTACT

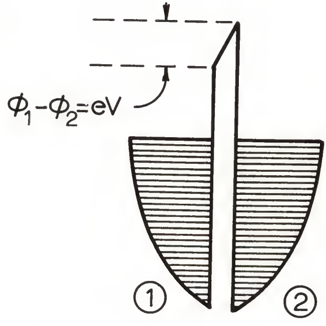
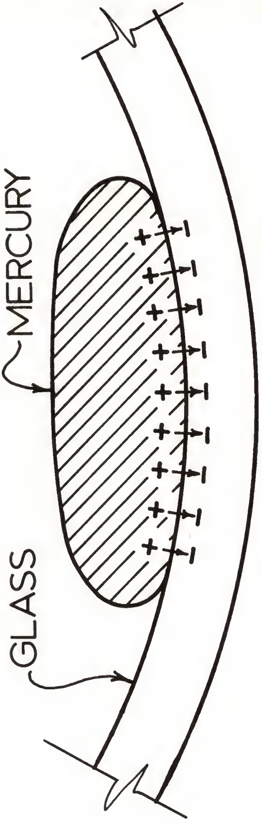


FIG. 2 AFTER CONTACT

EXPLANATION OF PLATE III

Where the mercury contacts the glass, electrons travel to the surface of the glass leaving the mercury with a positive charge and forming a potential barrier.

PLATE III



PARTIAL CROSS-SECTION OF A MERCURY-GLASS SPHERE spheres show that the mercury becomes positively charged.

Assuming that the charge equilibrium is now established, the effect of mechanical motion on the system will be described. Let the motion be a constant rotation about any axis through the sphere center. At the leading edge of the mercury-glass interface, the charges will start to separate on rotation due to the relative immobility of the electrons on the glass. As the rotation continues, the charges become more widely separated, the positive charges in the mercury conductor (9.6×10^{-5} OHM-CM) distributing themselves so as to maintain electronic neutrality and remaining as close as possible to the electrons owing to Coulomb attraction. This development appears in Fig. 1, Plate IV. A point is reached, however, where the separation approaches the mean free path of an electron in the gas, and the potential energy between the separated charges becomes so great that the dielectric strength of the gas is exceeded, and the gas breaks down forming the observed glow. The gas pressure is thus seen to play a large role in the effect, since too many or too few gas atoms prevent the best conversion of the energy into light (Fig. 2, Plate IV). After the break-down, the charge on either side of the mercury-glass potential barrier starts separating, and the break-downs continue to occur.

Let the cross-section of the ball be represented as in Plate V. Then, if there is one break-down when the glass moves a distance s, there will be $2\pi R/s$ break-downs per revolution and $2\pi R\omega/s$ break-downs per second. Assuming that each break-down lasts a very short time compared to the time required to develop the distance s, the light output is expected to consist of sharp light pulses, the number of which would

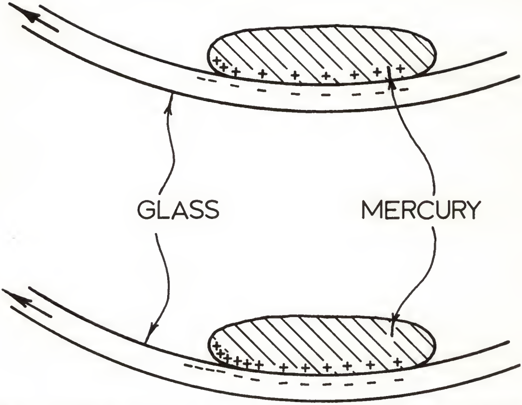
EXPLANATION OF PLATE IV

The Glow Mechanism

Fig. 1. As mechanical rotation starts the charges begin to separate, the positive charges moving in the mercury so as to remain as close as possible to the approximately immobile electron distribution.

Fig. 2. A discharge will take place in the gas in the sphere when the charges are separated by the mean free path of an electron in the gas. The break-down process will repeat itself on further rotation.

PLATE IV



TWO STAGES OF CHARGE SEPARATION

FIG. 1

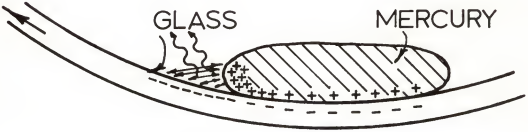


FIG. 2 BREAK-DOWN

EXPLANATION OF PLATE V

The Definition of Some Sphere Parameters

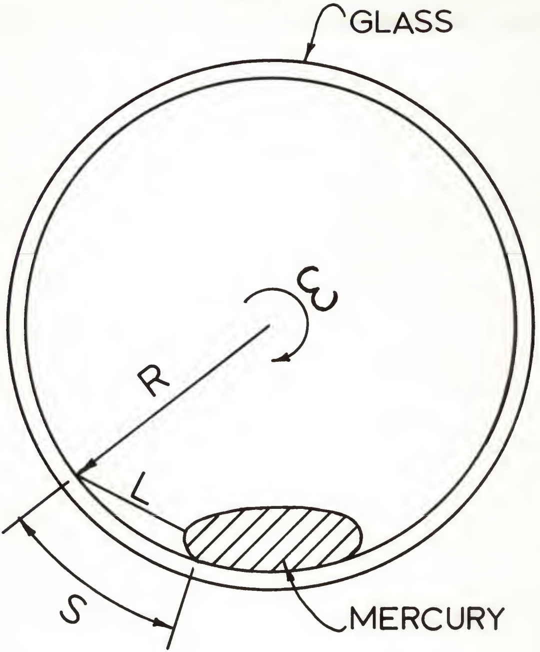
ω = rotation rate of the sphere in revolutions per second

R = inside radius of ball

s = arc length on the glass surface over which electrons are distributed just at break-down

L = minimum distance of separation of the leading charges at break-down.

PLATE V



CROSS-SECTION OF SPHERE

increase linearly with (Plate VI). The minimum separation of charge, L, can be found as a function of s if the geometrical model of the mercury-glass balls is as in Plate VII. The equation of the large sphere is $x^2+(y-R)^2 = R^2$. The equation of the small sphere is $x'^2+(y'-r)^2 = r^2$. Also

$$s = R\Theta$$

so

$$x = R\sin\Theta = R\sin s/R$$

$$y = R(1-\cos\Theta) = R(1-\cos s/R)$$

In general then

$$L^2 = (x-x')^2 + (y-y')^2$$

substituting:

$$L^2 = R^2\sin^2 s/R - 2R\sin s/R\sqrt{r^2-(y'-r)^2}+r^2-(y'-r)^2+\left[R(1-\cos s/R)-y'\right]^2$$

$$= L^2(s,y')$$

since s can be fixed by experiment, the y' value necessary to make L a minimum can be found by differentiation.

$$2L\frac{dL}{dy'} = 0 = \frac{-2R\sin s/R(-2[y'-r])}{\sqrt{r^2-(y'-r)^2}} - 2(y'-r) - 2\left[R(1-\cos s/R)-y'\right]$$

or

$$R\sin s/R(y'-r) = \left[r-R(1-\cos s/R)\right]\sqrt{r^2-(y'-r)^2}$$

Squaring and collecting terms in powers of y':

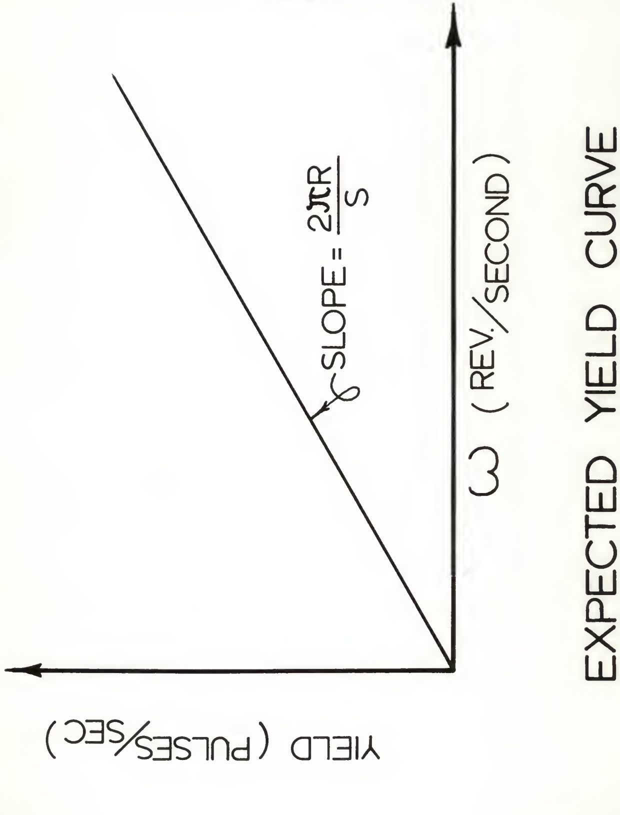
$$R^2\sin^2 s/R(y'^2-2y'r+r^2) = \left[r-R(1-\cos s/R)\right]^2(-y'^2+2y'r)$$

$$y'^2\left\{R^2\sin^2 s/R+\left[r-R(1-\cos s/R)\right]^2\right\} - y'2r\left\{R^2\sin^2 s/R+\left[r-R(1-\cos s/R)\right]^2\right\}$$
$$+ r^2R^2\sin^2 s/R = 0$$

EXPLANATION OF PLATE VI

For a pulsed output, a linear relationship is expected between the yield and the rotation rate. From such a curve, the physical arc length s for the sphere could be determined.

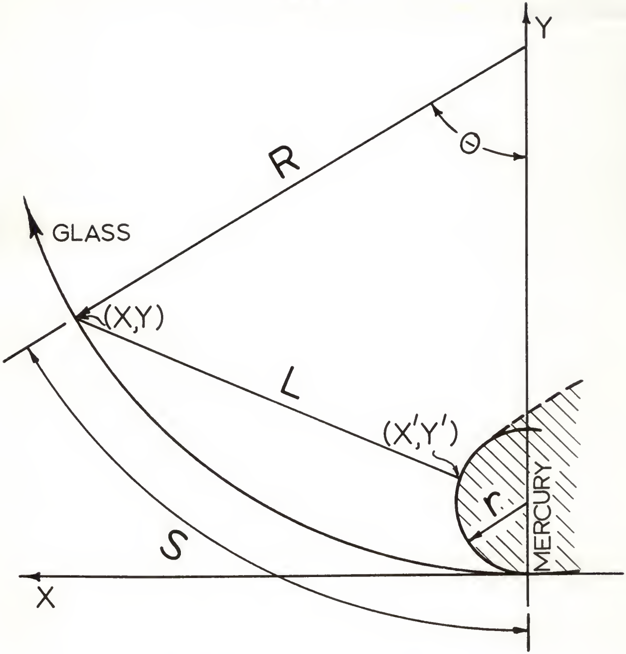
PLATE VI


EXPECTED YIELD CURVE
ω (REV./SECOND)
SLOPE = 2πR/S
YIELD (PULSES/SEC)

EXPLANATION OF PLATE VII

The approximate distance, L, at break-down between the charges which first seperated can be found as a function of the arc length s if a mathematical model is established with the bell radius R and the cross-sectional edge of the mercury puddle approximated by a semicircle of radius r.

PLATE VII



A MATHEMATICAL MODEL
OF THE SPHERE

then let

$$A = \left\{R^2 \sin^2 s/R + \left[r-R(1-\cos s/R)\right]^2\right\}$$

$$C = r^2R^2 \sin^2 s/R.$$

Hence

$$Ay'^2 - 2rAy' + c = o$$

so $$y'_{\substack{min\\L}} = \frac{2rA \pm \sqrt{4r^2A^2 - 4Ac}}{2A} = r \pm \sqrt{r^2 - C/A}$$

where the plus sign is chosen if

$$\left[r-R(1-\cos s/R)\right] < 0$$

and the negative sign in the case where

$$\left[r-R(1-\cos s/R)\right] > 0$$

then

$$L = \left[L^2(s, y'_{\substack{min\\L}})\right]^{1/2}$$

$$= \left[2R \sin s/R \left[r^2-(y'_{\substack{min\\L}} -r)^2\right]^{1/2} + (2R^2-2R)(1-\cos s/R) + 2ry'_{\substack{min\\L}}\right]^{1/2}$$

$$= L(s)$$

Apparatus was set up to test this pulse theory. A highly regulated constant speed motor was fitted with a metal cup on the drive shaft such that the glass spheres could be held in the cup by a spring loaded harness that fits over the top of the ball (Plate VIII). An ultraviolet sensitive Geiger counter (Plate IX) was placed under the ball and parallel to the axis of rotation (Plate VIII), and then connected to an electronic scalar (Plate X). The yield or counts/second versus rotation rate graph with this detector is shown in Plate XI. The evident thing in the graph is its non-linearity. This was

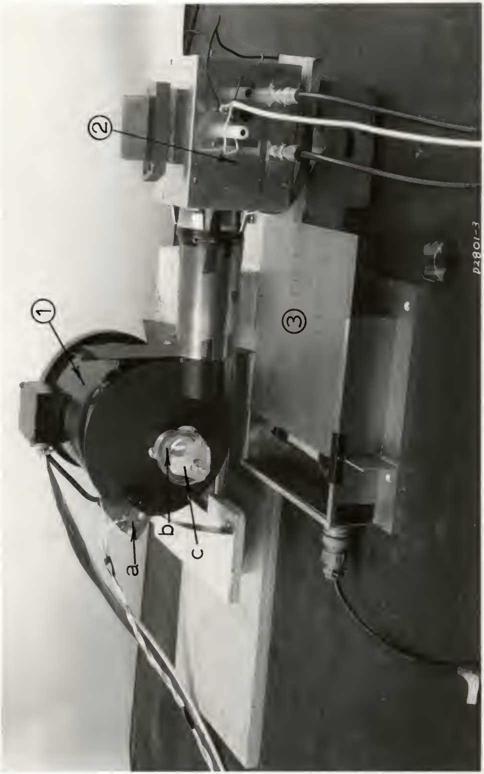
EXPLANATION OF PLATE VIII

1. Constant speed motor
   a. Revolution counter
   b. Ball
   c. Spring loaded harness

2. RCA C70128 U.V. sensitive photomultiplier tube and circuit

3. U.V. sensitive Geiger counter assembly

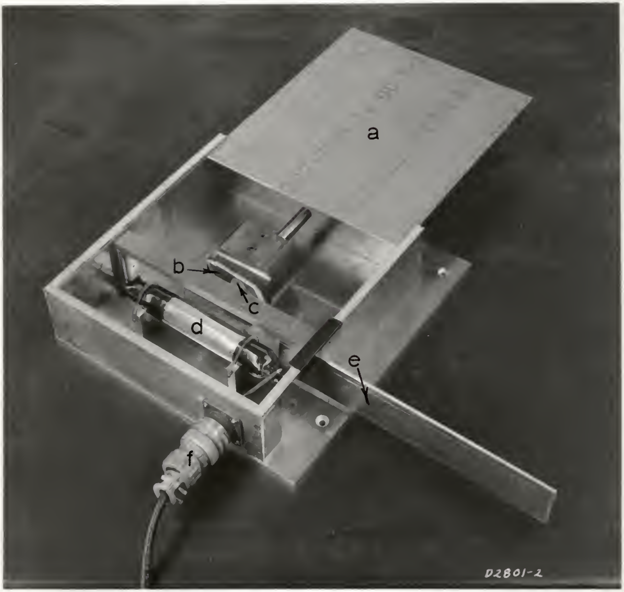
PLATE VIII



EXPLANATION OF PLATE IX

a. Cover
b. CaF_2 crystal slab } u.v. emitter for sensitivity
c. Plutonium source } checks on the Geiger tube
d. u.v. sensitive Geiger tube
e. Sensitivity check slide
f. High voltage input

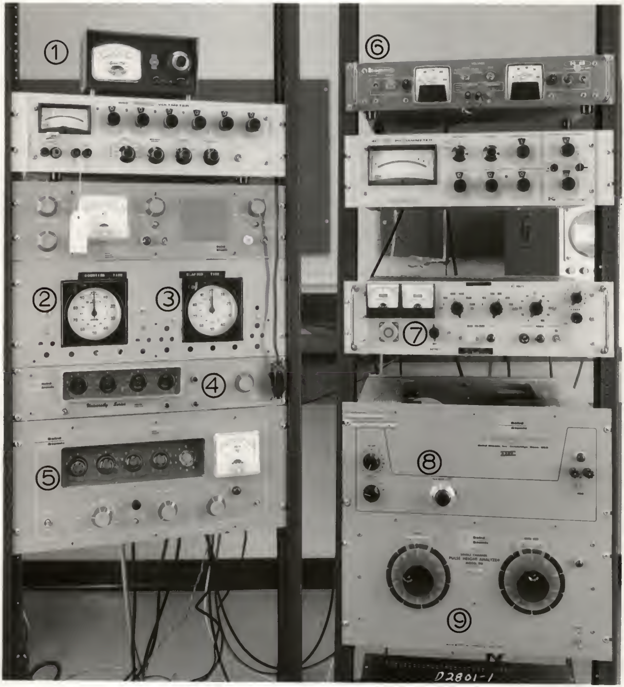
PLATE IX



EXPLANATION OF PLATE X

1. Rotation rate control box for the motor
2. Counting time clock
3. Length of experiment or elapsed time clock
4. Counter for the number of revolutions of the motor
5. Electronic scalar
6. Emitter-follower power supply
7. Photomultiplier high voltage supply
8. Non-overloading amplifier
9. Single channel pulse height analyzer

PLATE X



EXPLANATION OF PLATE XI

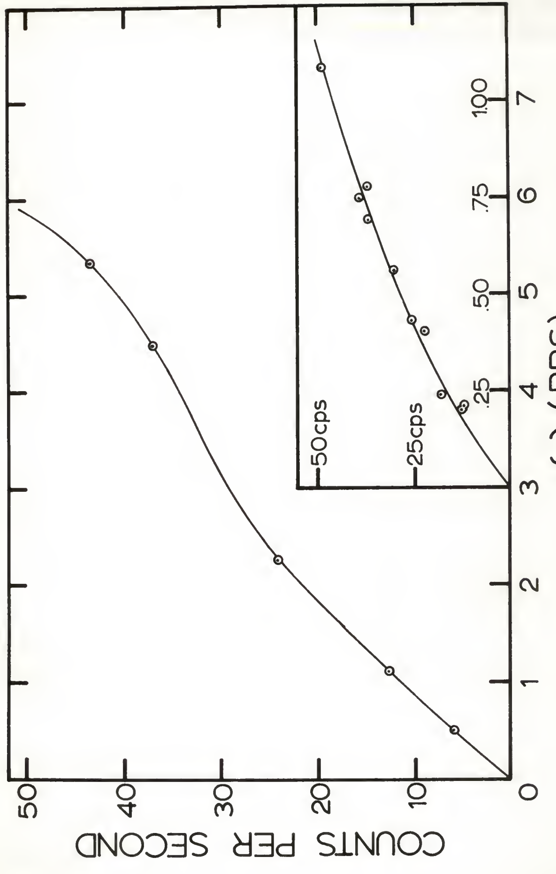
Output curves from the helium filled (0.6 mm Hg pressure) ball using the u.v. sensitive Geiger counter as a detector:

January 30, 1966
- Counter tube plateau = 1000 volts
- Conditions prior to experiment recorded
- No sensitivity checks on the tube were taken

Insert: This graph shows that the yield curve for this ball is not linear, even at slow rotation rates.

November 23, 1965
- Counter tube at 1100 volts
- Geometry change
- Curve corrected for small changes in tube sensitivity during the 3.5 hour data taking period

PLATE XI


COUNTS PER SECOND
ω (RPS)
0
10
20
30
40
50
1
2
3
4
5
6
7
50cps
25cps
.25
.50
.75
1.00

tentatively explained when it was realized that the Geiger counter counts a certain percentage of the incident photons, not pulses, which pass through it. Still, if each pulse contains the same number of photons, the yield of photons versus rps curve should still be a straight line. The next step was to develop a light pulse counting detector. This was done by using a photomultiplier tube the output of which was sent through a D.C. blocking capacitor, (Plate I), a non-overloading pulse amplifier, and then to the scalar (Plate X). The effect of the capacitor and amplifier is one of sending to the scalar only electrical pulses of a fixed height corresponding to each light pulse with a size above that of the background noise. The output curves from the sphere now appear as in Plate XII. The linearity bears out the basic correctness of the above described pulse theory. However, when the output from the same photomultiplier tube is sent directly into a simple integrating network so that the average value of the entire wave form is sent as a D.C. signal to a microvoltmeter (Plate X), the yield curve obtained is like that given in Plate XIII. The curve has the same general shape as in Plate XI which can be explained by the presence of a continuous excitation of the gas in the sphere over and above the pulse excitation assuming that the shape of a voltage pulse of any given height is not a function of ω. Some spheres have been found to emit radiation but not in pulse form, so a continuous radiation does exist.

An oscillogram of the electrical output signal from the A.C. photomultiplier corresponding to a light flash shows a pulse about 4 μ seconds wide at half the maximum amplitude with the rise and fall times

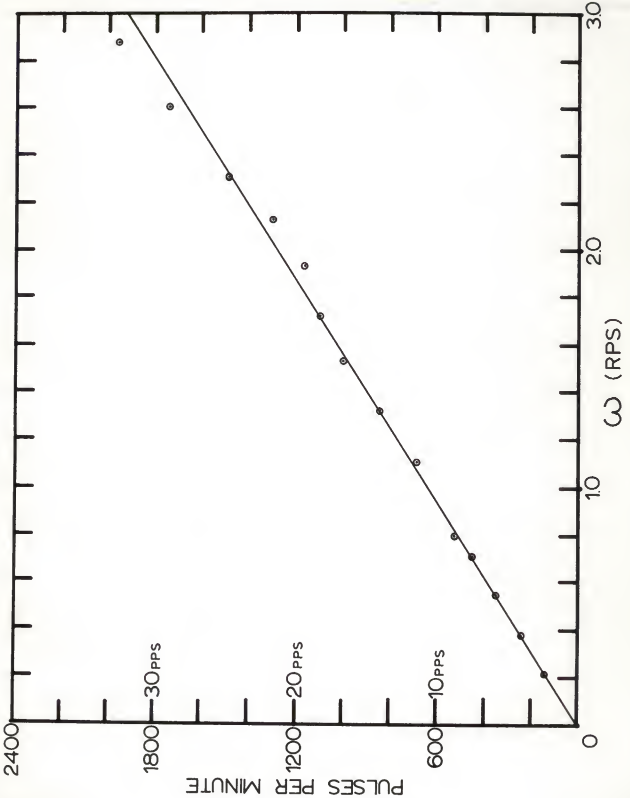
EXPLANATION OF PLATE XII

Pulse Counting Data

The yield is in pulses per minute (second) as a function of the revolution rate ω. The value of s for this ball was calculated from this graph.

February 18, 1966
- Photomultiplier tube - RCA 1P28
- Total dynode voltage - -800 volts
- Helium filled (0.6 mm Hg) ball

PLATE XII

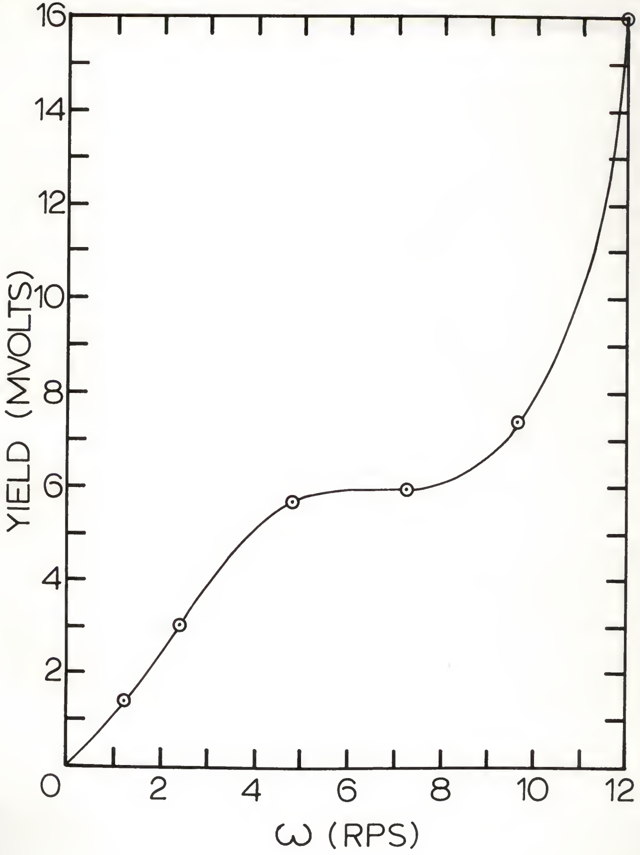

PULSES PER MINUTE
ω (RPS)
2400
1800
1200
600
0
30PPS
20PPS
10PPS
1.0
2.0
3.0

EXPLANATION OF PLATE XIII

This yield curve was obtained by finding the average D.C. voltage value of the photomultiplier wave form. The non-linearity shown is typical and holds for balls with different helium pressures.

July 10, 1966
- Photomultiplier tube - RCA C70128
- Total dynode voltage - -1350 volts
- Ball #6 - 20 mm Hg of helium

PLATE XIII



approximately equal. It is difficult to give an exact representation of a pulse since the electrical circuit components of the photomultiplier system have an effect on the output pulse shape and each light pulse is by no means identical with the next pulse, however the same general features were always observed.

Experiments with glass bells with electrodes (Plate I) show that 150 volt electrical pulses can be formed by induction from these breakdowns.

Three photomultiplier tubes (RCA C70128, RCA 1P28, RCA 7102), each with a different region of sensitivity, U.V., visible, and infrared respectively, showed that the light pulses contain radiation with wavelengths in each of these three spectral regions.

A check on the distribution of pulse heights at a fixed ω has been made with a single channel analyzer (Plate X), and a typical result is given in Plate XIV. This distribution shape holds over the entire linear portion of the pulse output curve.

An experiment to determine any polarization of the light pulses was made, and none was found.

CHARACTERIZATION OF THE DISCHARGE

A number of order of magnitude calculations can be made in an attempt to show the size of the effect. If the mercury-glass potential barrier is pictured as a parallel plate capacitor, the amount of charge on each plate can be determined by assuming a value for the contact potential difference and plate separation, thus determining the charge per unit area going from the mercury to the glass surface. A one volt

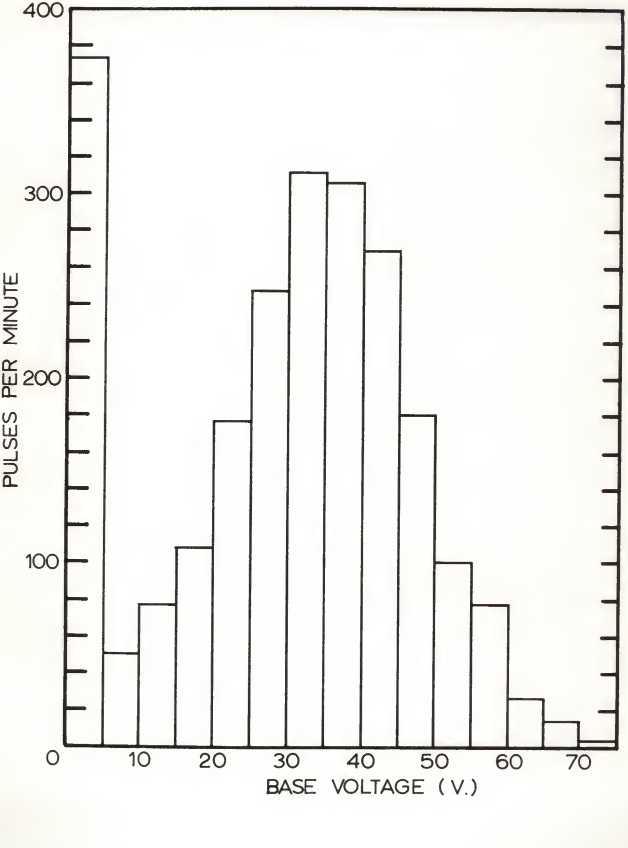
EXPLANATION OF PLATE XIV

All the light pulses from a given sphere are not equally intense. Their distribution in terms of pulse height is shown in the graph. The single channel analyser was set with a window of 5 volts, and the number of pulses per minute within this window and above the base voltage was then determined. The actual pulse heights for this experiment can be found by using base voltage divided by the amplifier gain which was 72. The large number of counts in the first interval was due to noise and small light pulses.

February 26, 1966

- Photomultiplier tube - RCA 1P28
- Total dynode voltage - -800 volts
- ω = 2.74 revolutions/second
- Helium filled (0.6 mm Hg) ball

PLATE XIV


400
300
200
100
0
10
20
30
40
50
60
70
PULSES PER MINUTE
BASE VOLTAGE (V.)

barrier 100 Å wide at the interface should be typical.

$$\sigma = \frac{Q}{A} = \frac{VC}{A} = \frac{\epsilon_o V}{d} \approx \frac{(1v.)(8.85\times10^{-12}\text{farad/m})}{100\ \text{Å}} = 9\times10^{-8}\ \frac{\text{coulombs}}{\text{cm}^2}$$

$$\text{i.e. } (9\times10^{-8}\ \frac{\text{coulombs}}{\text{cm}^2})(6.28\times10^{18}\ \frac{\text{electrons}}{\text{coul}}) = 5.7\times10^{11}\ \frac{\text{electrons}}{\text{cm}^2}$$

This is to be compared with the approximate number of glass molecules per cm^2, i.e., one layer thick

$$\frac{n}{A} = \left[\frac{(\text{Avagadro's number})(\text{Specific gravity})}{(\text{Glass molecular weight})}\right]^{2/3}$$

$$\approx 8\times10^{14}\ \text{molecules/cm}^2$$

That is, there is about one electron for 1400 surface glass molecules.

Now consider the charge in its separated condition just before break-down. From Plate XII, s can be found

$$\text{Yield} = 2\pi R\omega/s$$

$$s = \frac{2\pi R\omega}{\text{Yield}} = \frac{2\pi(2.42\ \text{cm})(1\text{rps})}{(10.7\ \text{pulses/sec})} = 1.419\ \text{cm}$$

And the separation of the charges at the widest point just at break-down is L and from above is found to be

$s = 1.419$ cm; $r = 0.15$ cm; $R = 2.417$ cm

$\cos s/R = 0.83255$; $\sin s/R = 0.55394$

$A = 1.8575$; $C = 0.0403$; $y'_{\min_L} = 0.178$ cm

$L = 1.263$ cm

A model capacitor of the same approximate size as that presented by the charges before break-down has a capacity of 2.6 pfd. Then

$$V = \frac{Q}{C} = \frac{\sigma A}{C} = \frac{\sigma s(\text{Hg puddle width})}{C} = \frac{(9\times10^{-8})(1.419)(1.7)}{(2.6\times10^{-12})}$$

$$\approx 83 \text{ K volts}$$

The energy in the capacitor at break-down is

$$\mathcal{E} = \frac{Q^2}{2C} = \frac{\sigma^2 s^2(\text{Hg puddle width})^2}{2C} \approx 0.009 \text{ Joule}$$

In general, the work required to separate the plates of the capacitor can be found from

$$\frac{W}{\text{Pulse}} = \int dW = \int F dx = \int \frac{\sigma^2 A}{2\epsilon_o} dx = \frac{\sigma^2}{2\epsilon_o} \int_0^{L_{\text{break-down}}} A(L)dL$$

and the work of charge separation for one revolution of the glass sphere is

$$\mathcal{W} = \frac{W}{\text{Revolution}} = \frac{2\pi R}{s}\left(\frac{W}{\text{Pulse}}\right)$$

If the glass sphere is in an otherwise force free space with an initial angular velocity ω_o, the ball will slow down as the rotational energy is converted to light pulses and heat from the mercury-glass frictional contact.

$$\mathcal{E}(t) = 1/2\left(I^{1/2}_{\substack{\text{Glass}\\ \text{sphere}}}\omega\right)^2 = 1/2 I\omega_o^2 - \left(\frac{W}{\text{rev.}}\right)\text{rev.} - (\mu N)\ 2\pi R(\text{rev.})$$

$$= 1/2 I\omega_o^2 - \left(\mathcal{W} + 2\mu N\pi R\right)\int_o^t \omega(t)dt$$

Differentiating this equation with $c = \left(\mathcal{W} + 2uN\pi R\right)/(\,I\,)$,

$$I\omega\dot{\omega} = -cI\omega$$

$$\dot{\omega} = -c$$

Then

$$\int_{\omega_o}^{\omega} d\omega' = -c\int_o^t dt'$$

$$\omega - \omega_o = -ct \quad \text{where } o \leq t \leq t_{stop} \quad \text{and}$$

$$t_{stop} = \frac{\omega_o}{c}$$

Then $$\xi(t) = \xi_{t=o} - Ic\int_o^t \omega(t)\, dt$$

$$\xi(t) = \xi_{t=o} - Ic(\omega_o t - \frac{ct^2}{2})$$

These results are graphed In Plata XV.

With the explanation and knowladge of the pulse natura of this effect, its behavior under varying conditions can be investigated. One such investigation is that of watching the development of the pulse counts as a function of time. The motor and ball were set up as previously dascribed, and the yield in pulses per second was monitored periodically using the photomultiplier-capacitor-amplifier detector (Plate VIII). The results are given in Plate XVI. A steady decraase appears first which levels off gradually, and just before the disappaarance of countable pulses, the emission is erratic being great or slight at random. The point of disappearance of the pulses is actually somewhat arbitrary. The amplifier is initially set so as to reject all pulses below a cartain height. The pulses from the photomultiplier itself were continuously displayed on an oscilloscope, and their distribution and shape appeared to remain the same during the entire experiment; only the number and heights of these pulses decreased. When the point in the experiment had baen reached whera no pulses wera counted, an incraase in gain of the oscilloscope amplifier showed that the ball was still emitting light of a pulse nature albeit very weakly; in fact, a visual check at this point showed no

EXPLANATION OF PLATE XV

For a sphere rotating initially at ω_0 (initial energy E_0) and emitting light pulses,

Fig. 1. The rotation rate decreases linearly with time until the rotation ceases altogether.

Fig. 2. The energy decreases parabolically with time until the rotation ceases altogether.

PLATE XV

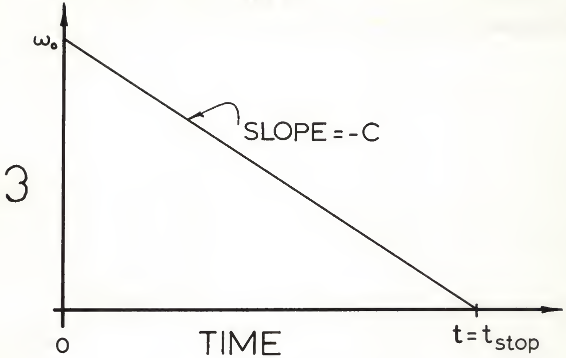


FIG. 1

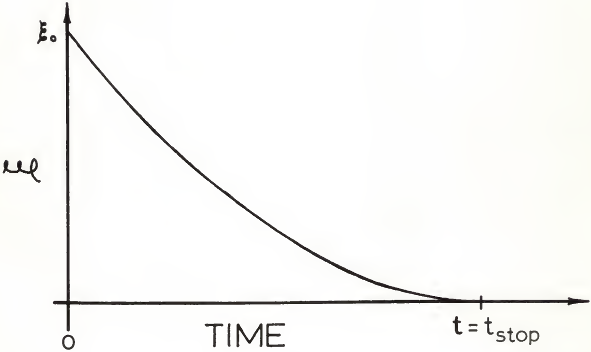


FIG. 2

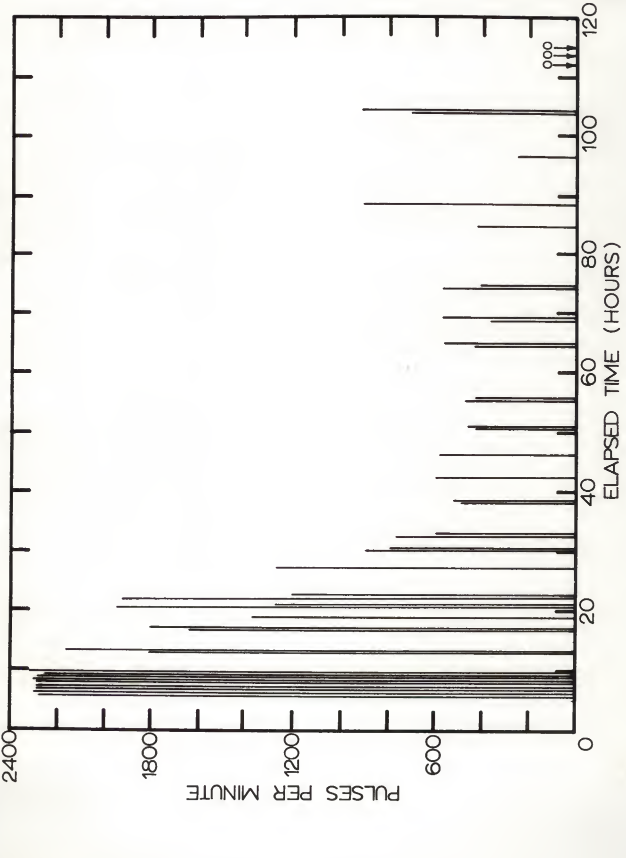
EXPLANATION OF PLATE XVI

This graph shows the output nature of a ball revolving at $2.583 \pm 0.038_{max}$ rps as a function of time. The main period of decrease lasted until 33 hours, the output then stabilized, and at 80 hours the yield was erratic until about 110 hours when any pulses still being emitted were very small.

Started May 15, 1966

- Photomultiplier - C70128
- Total dynode voltage - -1500 volts
- Helium filled (0.6 mm Hg) ball (irradiated for 60 minutes with a mercury lamp prior to the start of the experiment)

PLATE XVI


PULSES PER MINUTE
2400
1800
1200
600
0
ELAPSED TIME (HOURS)
20
40
60
80
100
120

discernable glow at all. Viewed under room lighting, the surface of the glass which had been in contact with the mercury was visible at the end of the experiment as a cloudy black band circling the sphere. It has already been shown that light in pulses is not the total radiation from the ball, and actually the above time effect should be noted for the entire emission from a sphere. The U.V. sensitive Geiger counter gave the same general curve shape (Plate XVII). The mercury-glass system does seem to recover slowly its pulse forming capability after such long run times (~ 5 days), but whether or not the recovery is complete remains a question. This partial recovery seems to suggest that during a long running time the ball surface slowly becomes "clogged" with mercury such that in places there is no potential difference when the mercury puddle rolls over it, thus reducing the number of pulses. In other places on the surface, the potential difference is effectively reduced, and the light pulses produced are consequently less intense than normal. With the cessation of rotation the surface gradually reverts to its initial condition. Some of the observed cloudiness on the glass surface may be "mercury blackening" however, which is the term used to describe the chemical change of the surface due to a prolonged presence in a region of electrical break-down of mercury vapor. This time effect shows that the present behavior of a ball is to some degree affected by its past history, thus making quantitative, reproducible measurements on the ball difficult--even the more so between different balls.

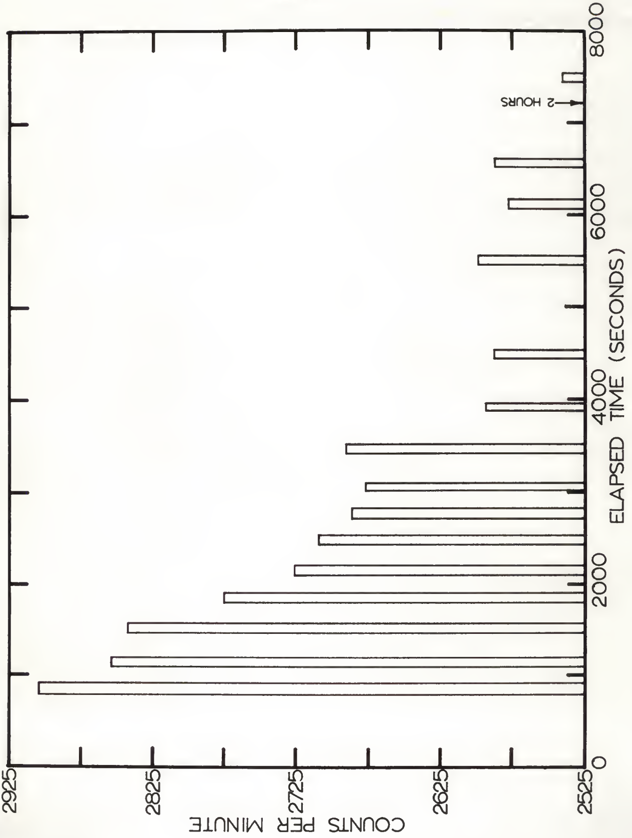
EXPLANATION OF PLATE XVII

The trend towards the reduction of the total radiation output with time is shown in this graph.

October 20, 1965

- Tube voltage - 1100 volts
- Background count 46 cpm (No correction made on graph)
- $= 4.28 \pm 0.058_{max}$ rps
- Helium filled (0.6 mm Hg) ball
- A correction of 15 counts per rev. was made for those trials where the rps differed from the average (correction small compared to the count rate during the experiment)

PLATE XVII


COUNTS PER MINUTE
2925
2825
2725
2625
2525
ELAPSED TIME (SECONDS)
0
2000
4000
6000
8000
2 HOURS

FUTURE WORK

This effect has many other interesting physical ramifications and unexplained characteristics. Some of these which will be worked upon in the future are as follows:

1). The electrons which move from the mercury to the glass are assumed to be stationary on the glass as the charges are separated by the rotation of the sphere. In reality, however, these electrons do have a mobility since the stated values for the surface conductivity of glass are not zero. It is hoped that by slowing down the rotation enough, a point will be reached where pulse forming break-downs no longer occur due to the motion of the electrons back towards the vicinity of the mercury puddle with its potential barrier which produced them. This revolution rate would then indicate the mobility of the electrons in their surface states.

2). When mercury is placed in contact with the glass there must be a finite time within which the electrons flow onto the glass, and the potential barrier is established. Thus if mercury in contact with glass is moved fast enough, supposedly no break-downs would occur due to a lack of sufficient electrons on the glass. This effect may be difficult to detect if the flow time is short since a rapid rotation of these spheres changes the shape of the mercury puddle, and splashing and bouncing ruin completely any hope for obtaining reproducible results.

3). A quantitative analysis of the effect is yet to be formulated which would account for differences in the observed effect because of differences in the types of glasses used. The glow intensity will change for different barrier heights which are controlled by both the glass and the mercury. Glasses with high surface conductivities, as for example Corning 0080, would more easily show the effect described in section 1) above. Some idea of the number of surface states versus the type of glass might also be obtained. Such measurements of the properties of glass surfaces could be important in developing a mercury-glass system with an output intense enough for some practical importance as a light source.

4). The exact energy distribution of the ratiation within the pulse outputs has not been fully determined. The Japanese articel (1) shows a microdensitometer tracing for the near U.V. and visible spectrum regions, and an infrared photomultiplier shows that there is radiation in this region also. The presence of spectral lines of ionized atoms will be investigated, as well as general spectral changes due to the changing of other variables such as time and ω .

5). The presence of the experimentally observed continuous glow as apart from that due to pulses must also be explained. Its yield is also a function of the rotation rate, but it is not linear as for the light pulses.

6). The vapor pressure of mercury changes markedly with temperature, and the number of mercury vapor atoms in the gas atmosphere may cause large changes in the character of the break-downs since, for the case of inert helium in a ball, the mercury atoms have the lowest excitation potentials and hence should control much of the radiation. Thus, temperature versus yield curves should be related to the efficiency of the charge discharge mechanism.

7). Some investigations have already been made into the possible practical use of the electrical nature of the sphere devices. For example, it can be thought of as an extreme case of a diode transistor with the mercury a "good" semiconductor and the glass surface a "poor" conductor. It is just this fact that the glass has a high resistivity that seems to remove the device from any practical usage considerations (Plate XVIII).

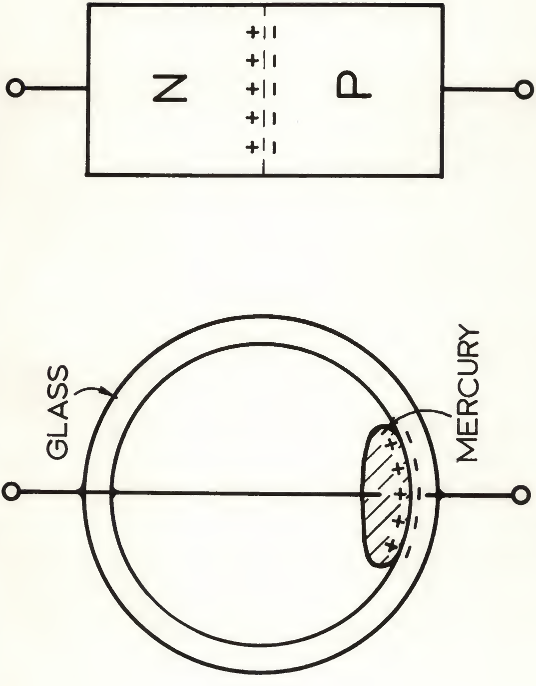
SUMMARY

The summary with results is contained in the abstract.

EXPLANATION OF PLATE XVIII

The mercury-glass sphere can be thought of electrically as an extreme example of a semiconductor diode device.

PLATE XVIII



SPHERE - TRANSISTOR ANALOGY

ACKNOWLEDGEMENT

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PROPERTIES OF GLASS VOLUMES CONTAINING MERCURY

by

GAY LEON DYBWAD

B. S., University of North Dakota, 1964

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Physics

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

The observation of visible radiant emission from mercury glass devices under partial vacuum and mechanical agitation is not new. The effect has not been extensively studied. Interest has been regenerated however by the hope of developing this effect into something of practical importance for the conversion of mechanical energy to light energy.

This work attempts to develop a simple theory of the light output by first setting up a potential barrier between the mercury-glass interface so that when the device is mechanically rotated, the charges maintaining the potential separate until an electrical break-down takes place in the gas forming the observed glow. The theory predicts that the number of light pulses should increase linearly with revolution rate. Subsequent experimental evidence confirmed the pulse nature of the output as well as its linearity. Continuously emitted radiation was also observed, but the theory does not predict its presence.

Some reasonable values for various physical parameters associated with the ball were selected and others are then calculated from these in an attempt to numerically characterize the pulse nature of the effect.

Several experiments were conducted to determine other properties of the device and the observed effect: the mercury is positively charged; the light is not plane polarized; the pulse intensities are not the same but form a continuous distribution about a central maximum, and the number and size of the light pulses decreases with time for a fixed revolution rate.

Some of the ideas and experiments which are being scheduled in order to determine more of the properties of the effect include spectroscopic observation of the light glow over a wide wavelength interval, determining electron mobilities in surface states on glass, finding the electron flow time from mercury to glass, observing what effect temperature has on the yield, and measuring the electrical properties of the mercury-glass interface.