PATENT SPECIFICATION

817,571

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International Classification:—G21.

COMPLETE SPECIFICATION

Means for Testing Materials

We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, of London, a British Authority, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described in and by the following statement:—

The present invention relates generally to the subject of nuclear physics and more particularly to means for determining neutron absorption in graphite, or other neutron slowing material.

An artificial source of neutrons is employed, and these neutrons are emitted into a mass of neutron slowing material or moderator. The neutrons thus emitted are fast neutrons and are slowed down in the slowing medium by a diffusion process during which the neutrons collide many times with nuclei of the medium, resulting in the loss of energy until the neutrons are finally slowed to thermal energy. Neutrons which have reached thermal energy continue to diffuse through the moderator, but without further loss of energy until they are finally absorbed in the moderator or in some other element present as an impurity in the moderator. The length of the path of the thermal neutrons during diffusion depends upon the absorption characteristics of the particular mass of slowing material employed due to the various amounts of impurities in different kinds of moderators. The present invention has to do primarily with the absorption of neutrons that have reached thermal energy, and more particularly provides a method for comparing the absorption of these thermal neutrons in different grades of graphite.

According to the invention means for determining neutron absorption of a neutron slowing down medium comprising a regularly shaped mass of the slowing down medium, a source of neutrons in the said mass, an efficient thermal neutron absorber at least partially surrounding the mass substantially to prevent the escape from and entrance into the mass of thermal neutrons, the said mass being provided with means for selectively placing a neutron detector at positions in the mass at predetermined distances from the neutron source, a portion of the absorber being removable so that comparative reading may be made with and without the removable portion.

The source of neutrons may be backed with a neutron scattering material. The source may be backed with a neutron reflector which is preferably of graphite.

The means may be backed by means reflecting neutrons from the source into the mass.

The following are ways of carrying the invention into effect, reference being made to the accompanying drawings in which:

Fig. 1 is a front elevational view of a graphite column covered on five sides with cadmium;

Fig. 2 is a top plan view of the column shown in Fig. 1;

Fig. 3 is a vertical sectional view taken on the line 3—3 of Fig. 1, showing in broken lines the cadmium sheet partially removed from the upper face of the graphite;

Fig. 4 is a horizontal section view taken on the line 4—4 of Fig. 3;

Fig. 5 is a front elevational view of a second embodiment of the present invention wherein the graphite is arranged in the form of a sphere surrounded by a cadmium absorber and by a water or paraffin shield; and

Fig. 6 is a horizontal sectional view taken on the line 6—6 of Fig. 5.

For purposes of the formulae hereinafter set forth, the following symbols are defined:

n_1 is the density of thermal neutrons without cadmium;

n_2 is the density of thermal neutrons with cadmium in place;

n is the difference $n_1—n_2$;

λ is the mean free path for scattering of thermal neutrons by carbon;

[*Price 3s. 6d.*]

Price 4s 6d

λ_D is the diffusion mean free path, and is given by the relation $\lambda = \lambda_D$ (1.—$\overline{\cos}\ \theta$) where $\overline{\cos\theta}$ is the mean value of the cosine of the angle between the direction of motion of a neutron before and after a collision;

v is the mean velocity of thermal neutrons;

D is the diffusion coefficient of neutrons in graphite and is equal to $\frac{1}{3}\ \lambda_D v$;

Δn is the Laplacian of n and is the sum of the three partial derivatives of n with respect to three rectangular axes;

$D\Delta n_1$ is the net loss in neutrons in a cubic centimeter per second due to diffusion;

q is the number of thermal neutrons produced per cm.^{3} per second;

δ scatt is the mean scattering cross-section of carbon and impurities for thermal neutrons;

δ cap is the mean capture cross-section of carbon and impurities for thermal neutrons;

N is the number of impacts by thermal neutrons before being captured and is equal to δ scatt/δ cap;

A_{jk} is a constant multiplier of the term j, k in a series;

L is called the "diffusion length" and is $\sqrt{\frac{1}{3}N\lambda\lambda_D}$,

a is the length of the side of the carbon block increased by the factor $2\lambda_D\sqrt{3}$;

b is the height of the carbon block increased by the factor $\lambda_D/\sqrt{3}$.

In a graphite structure wherein neutrons are diffusing, assuming that the number of impacts by thermal neutrons in graphite is large, the neutron density at any point is governed by the equation

$$D\Delta n_1 - \frac{v}{N\lambda} n_1 + q = 0 \qquad (1)$$

The first term is the loss per second due to diffusion, the second is the loss per second due to capture and the last term is the gain due to the production of thermal neutrons by the slowing down of fast neutrons from the source. Two sets of measurements are taken. In one of these a thermal neutron density distribution n_1 is set up. In the second a different distribution n_2 is measured resulting from the same rate of production q at every point, but with a new boundary condition brought about by introduction of cadmium which absorbs the thermal neutrons. The difference $n_1 — n_2 = n$ this satisfies the equation obtained by writing (1) for each and subtracting. The equation for n then takes the alternative forms:

$$n - \tfrac{1}{3}\ N\lambda\lambda_D\ .\ \Delta n = 0 \qquad (2)$$

$$n - L^2\ .\ \Delta n = 0 \qquad (2a)$$

By measuring the thermal neutron densities n_1 and n_2 throughout the graphite structure Δn and n may be computed. It is found that the ratio $\Delta n/n$ is a constant value, from which L^2 or 1/3 $N\lambda\lambda_D$ may be deduced by (2) or (2a). In the usual application of this invention different grades of graphite are tested, and if impurities are present the quantity N, the number of impacts the thermal neutrol makes before capture. is diminished. Consequently the values found for 1/3 N $\lambda\lambda_D$ and L^2 will be much smaller than for pure graphite and the purity of the graphite with respect to neutron capture is specified by the value of L. In case a numerical value for the mean capture cross-section in the graphite is desired it may be deduced from 1/3 N $\lambda\lambda_D$ using the known values of the scattering free path and scattering cross-section in graphite.

It is obvious that $\Delta n/n$ may be observed in the interior of a structure of any shape or size as long as it is large compared with the collision free path so that an appreciable number of thermal neutrons is formed. Also, the difference between n_1 and n_2 may be brought about by disposing the cadmium in any desired manner. The cadmium may partially or completely cover the structure of graphite; it may be arranged symmetrically or unsymmetrically. Two embodiments of the invention are disclosed and each has a high degree of symmetry, and consequently the two are particularly convenient for facilitating exact measurements. It is found that the measured values of n fit a mathematical formula and from this $\Delta n/n$ and consequently L may be readily found.

Referring to Figs. 1 to 4, one embodiment of the invention is shown. A column of graphite 24 in the form of a rectangular parallelepiped is built to a size 122 cm. by 122 cm. by 152.5 cm. This graphite column or block is covered on five sides by thermal neutron absorbing material such as cadmium sheets indicated at 25 and having a thickness of 0.45 grams per square centimeter. On the sixth side (at the top as shown in Fig. 3) a removable cadmium sheet 26 is employed. Adjacent to this sixth side is a paraffin block 27 provided with an open space 28 between the body portion 27[1] of the paraffin and the graphite column 24 and surrounded on its top and sides by paraffin. In the centre of this paraffin block 27 is placed a neutron source 29 which for purposes of illustration may be a combination of radium and beryllium. A plurality of slots 30 extend horizontally into the carbon block 24 providing a passage for the introduction into the graphite block of a rhodium or indium detector illustrated at 19 in Fig. 4. For purposes of measuring the neutron activity throughout various positions in the column 24 detector 19 may be placed at a number of different positions, as, for example, at three positions indicated by the x's in Fig. 4 in each slot

30, so that, in all, 45 different locations are assumed by the detector 19 and readings are made at each location. The detector is allowed to remain at each position in the graphite for a given length of time and is subjected to the bombardment of neutrons emanating from the neutron source 29. The radioactivity induced in the rhodium or indium is measured by the number of counts produced in a Geiger counter tube which is exposed to the beta rays emanating from the exposed rhodium or indium sheet.

The activity of the detector is measured for the 45 different positions in the graphite column 24 during which time the cadmium sheet 26 is in place on the upper surface of the column between the graphite and the neutron source 29. Following the taking of these readings the cadmium sheet 26 is removed and then similar readings again are made at the 45 positions throughout the graphite column 24.

The activity in the detector in the two cases is due in part to the resonance neutrons and in part to the thermal neutrons. The first part is not affected by the introduction of the cadmium sheet, so that the difference in the activities, with and without the cadmium, is proportional to the difference $n_1 - n_2$ between the densities of the thermal neutrons in the two cases. This difference satisfies equation (2) or (2a) with the appropriate boundary conditions.

To determine the quantity L^2 or $1/3\lambda\lambda_D N$ it is convenient to compare the observed differences (n) with a solution of the differential equation. The boundaries at which n is zero are removed a distance $\lambda/\sqrt{3}$ from the actual surfaces of the carbon block.

With the regular geometrical structure shown in Fig. 1, it is found that the difference of the thermal neutron densities (n) agrees with the following mathematical expression:

$$n = A \sin\frac{\pi x}{a} \sin\frac{\pi y}{a}\left[e^{-\alpha Z} - e^{-Z\alpha b} e^{\alpha Z}\right] \qquad (3)$$

where

$$\alpha^2 = \frac{3}{\lambda\lambda_D N} + \frac{2\pi^2}{a^2} \text{ or } \alpha^2 = \frac{1}{L^2} + \frac{2\pi^2}{a^2} \qquad (4)$$

In this the origin of the three rectangular coordinates x, y, a is at one corner of the face nearest the source. This face is a square whose side a is greater than the actual side of the carbon block by $2\lambda/\sqrt{3}$ and b is the length of the carbon block in the vertical direction increased by $\lambda/\sqrt{3}$. In the specific example shown herein a = 123.4 cms. and b = 153.9 cms. The solution (3) is the first term of a series which forms the precise mathematical solution of (2) with the disclosed boundary conditions. It has been found that the second higher term of the complete solution, viz:

$$n = \Sigma A_{jk} \sin\frac{\pi jx}{a} \sin\frac{\pi ky}{a}\left[e^{-\alpha jk Z} - e^{Z\alpha j k^b} e^{\alpha jk Z}\right] \qquad (5)$$

where

$$\alpha^2 jk = \frac{1}{L^2} + \frac{\pi^2}{a^2}(j^2 + k^2) \qquad (6)$$

represents a small correction.

From (4) it is evident that L or $N\lambda\lambda_D$ may be found when α is known. This may be deduced from the observations n, taken for different values of a down the middle of the structure shown in Fig. 1 where $x = \frac{a}{2}$ and $y = \frac{a}{2}$. The value of n according to (3) varies as:

$$e^{-\alpha Z} - e^{-Z\alpha b} e^{\alpha Z} \qquad (7)$$

The second term represents a small correction except very close to the end of the column. Apply this to the values of n, the logarithm of the corrected values would be expected to decrease linearly with a. From the slope as plotted $\alpha = .0424$ using (4) the diffusion length L is 45 cms. This corresponds to a capture cross-section of 4.5×10^{-27} cms.^{2}. If the graphite had been completely non-absorbing of neutrons, N and L would have been infinitely great, and the loss of thermal neutrons would have been due entirely to leakage. In that case from (4) $\alpha = \sqrt{2}\,\pi/a = .0361$.

With different samples of graphite, different values of L are found, depending on the purity of the graphite.

Referring to Fig. 5, a second embodiment of the invention is shown. In this form, the graphite is arranged in a sphere 35, approximately 100 to 140 centimetres in diameter.

Surrounding the graphite is water or paraffin 36. A plurality of slots 37, 38, 39, 40, and 41 are arranged in parallel relationship and project into the graphite cylinder approximately to the central axis. At the centre of the sphere is a neutron source 42, for example of radium and beryllium. Surrounding the graphite sphere 35 is a thin layer of cadmium 43, which is removable from the sphere.

In this form of the invention, readings are first made with the cadmium sheet 43 removed, and as before a suitable detector foil, such as indium, is inserted in each of the slots 37 and 41 and exposed to bombardment of neutrons so as to determine the neutron density distribution from the centre to the outside of the graphite sphere. Similarly, readings are made with a cadmium sheet 43 in place, so as to obtain a second set of readings to determine the new neutron density distribution from the centre to the outside of the sphere under these conditions. The first set of readings will show a certain distribution of neutrons from the centre to the outside of the graphite sphere, and since the cadmium sheet is not employed when making this first set of readings the neutron intensity at the surface of the sphere will be greater than zero. By surrounding the graphite sphere with cadmium, the thermal neutron intensity at the surface of the sphere is reduced to zero because the cadmium absorbs thermal neutrons which otherwise would leave or enter the surface of the sphere to or from the water or paraffin shield 36 surrounding the graphite. By reducing the thermal neutrons at the surface of the sphere to zero in this manner, the neutron intensities throughout the graphite sphere will vary from those existing when the cadmium sheet is removed.

In this second embodiment of the invention, the differential equation (2) in polar coordinates takes the form:

$$\frac{d^2(nr)}{dr^2} = \frac{nr}{L^2} \qquad (8)$$

which has the solution:

$$n = \frac{c}{r}\left(e^{\frac{r}{L}} - e^{-\frac{r}{L}}\right) \qquad (9)$$

L can be found by substituting the value of n for two values of r, for instance for r = o and r = r. The ratio of these two values n is:

$$\frac{L}{2r}\left(e^{\frac{r}{L}} - e^{-\frac{r}{L}}\right) \qquad (10)$$

from which L can be determined.

While we have described our invention as applied specifically to the measurement of graphite as a neutron slowing material, it will be obvious that our invention can equally well be applied to the determination of neutron absorption in other neutron slowing materials such as, for example, beryllium, heavy water, and the like.

Having now particularly described and ascertained the nature of our said invention, and in what manner the same is to be performed, we declare that WHAT WE CLAIM IS:—

Means for determining neutron absorption of a neutron slowing down medium comprising a regularly shaped mass of the slowing down medium, a source of neutrons in the said mass, an efficient thermal neutron absorber at least partially surrounding the mass substantially to prevent the escape from, and entrance into, the mass of thermal neutrons, the said mass being provided with means for selectively placing a neutron detector at positions in the mass at distances from the neutron source, a portion of the absorber being removable so that comparative readings may be made with and without the removable portion.

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Chartered Patent Agent.

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817,571 COMPLETE SPECIFICATION
3 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEET 1

FIG.1.

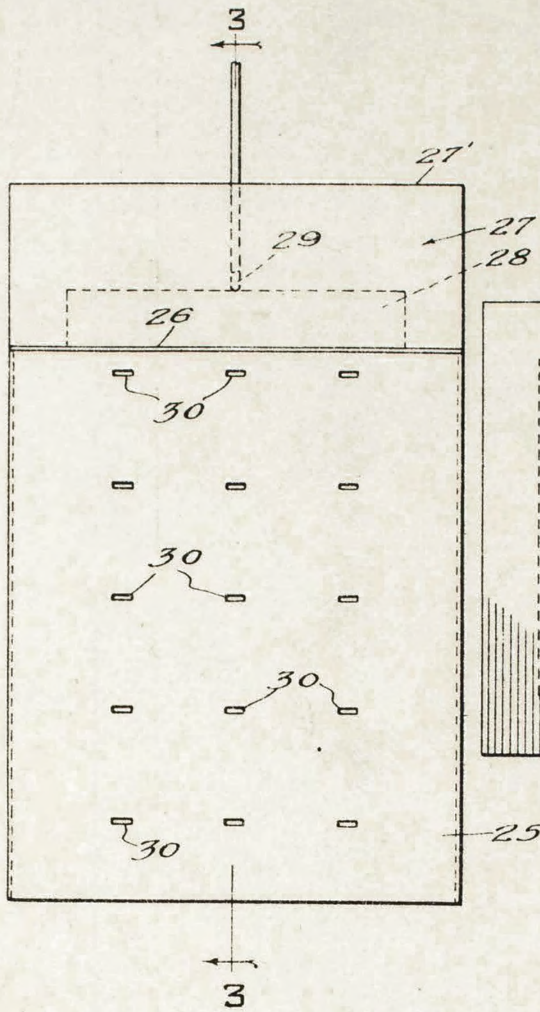
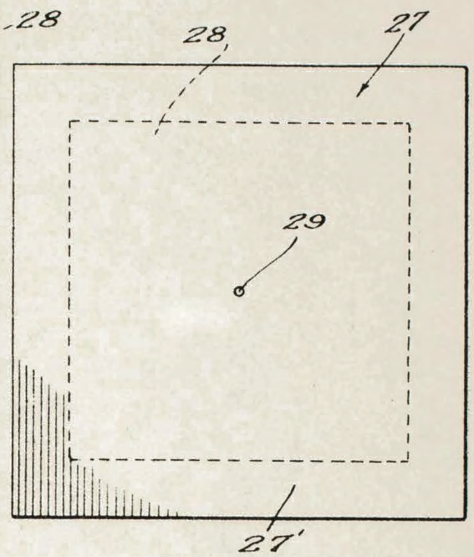


FIG.2.



817,571 COMPLETE SPECIFICATION
3 SHEETS
This drawing is a reproduction of the Original on a reduced scale.
SHEETS 2 & 3

FIG.3.

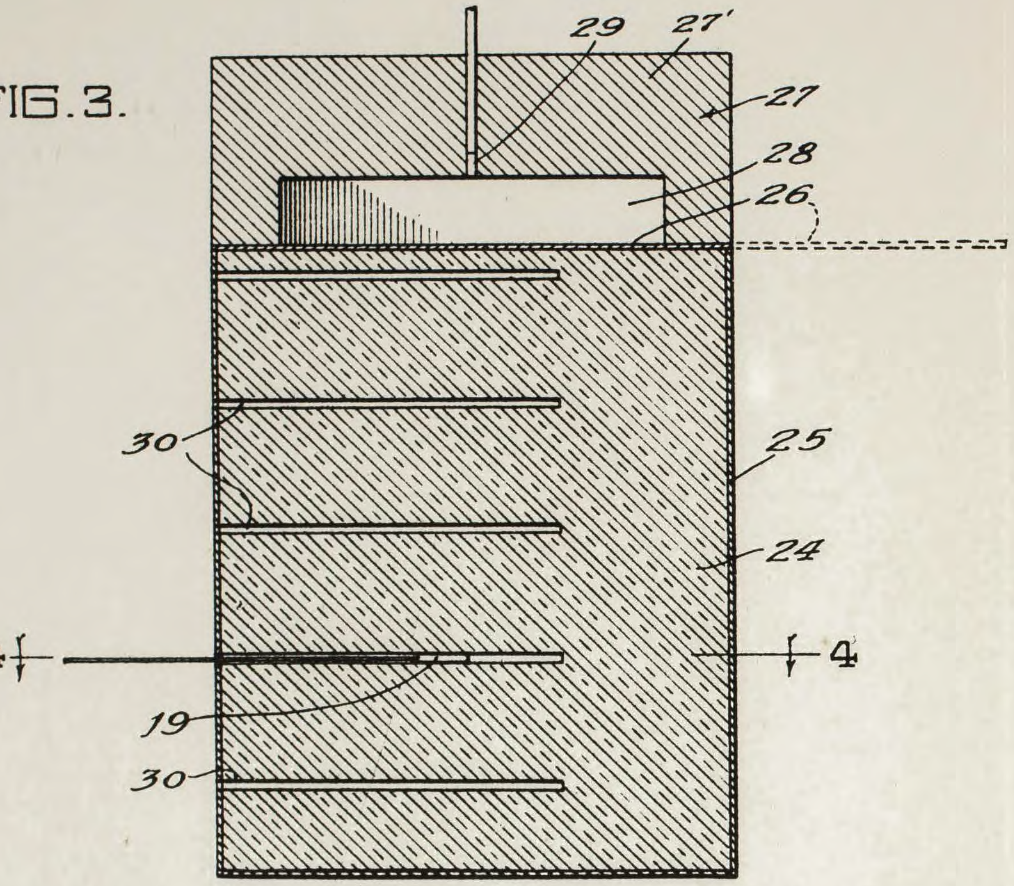


FIG 4

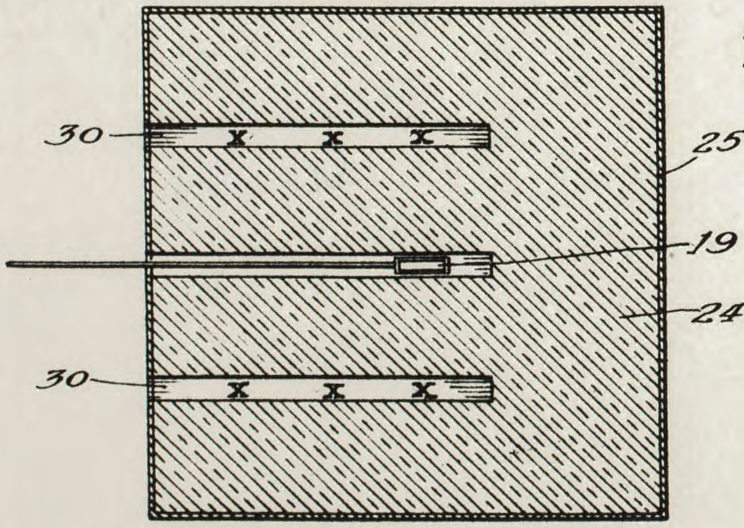


FIG.5.

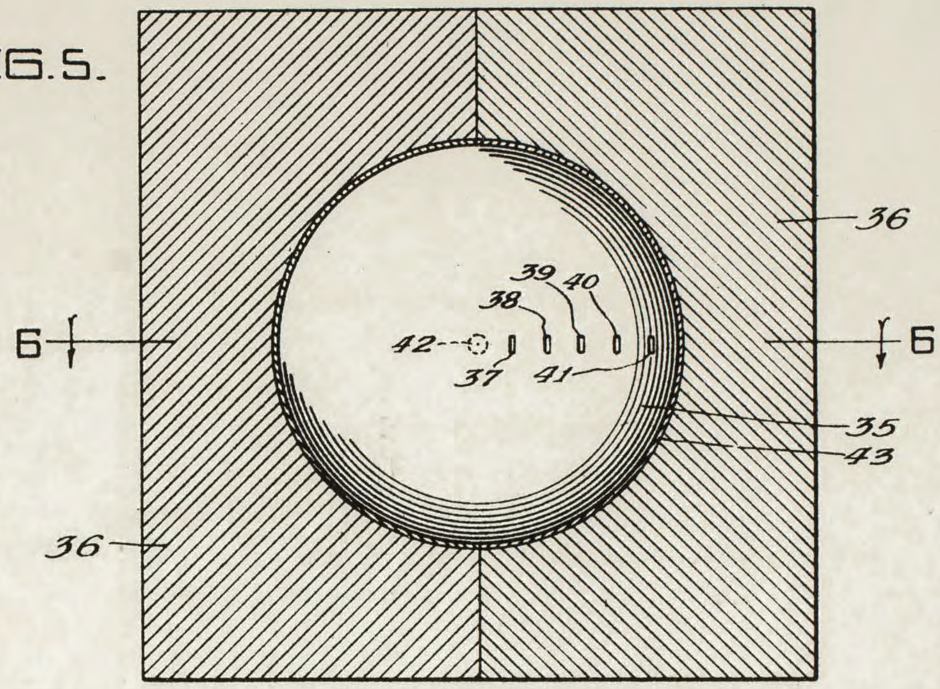
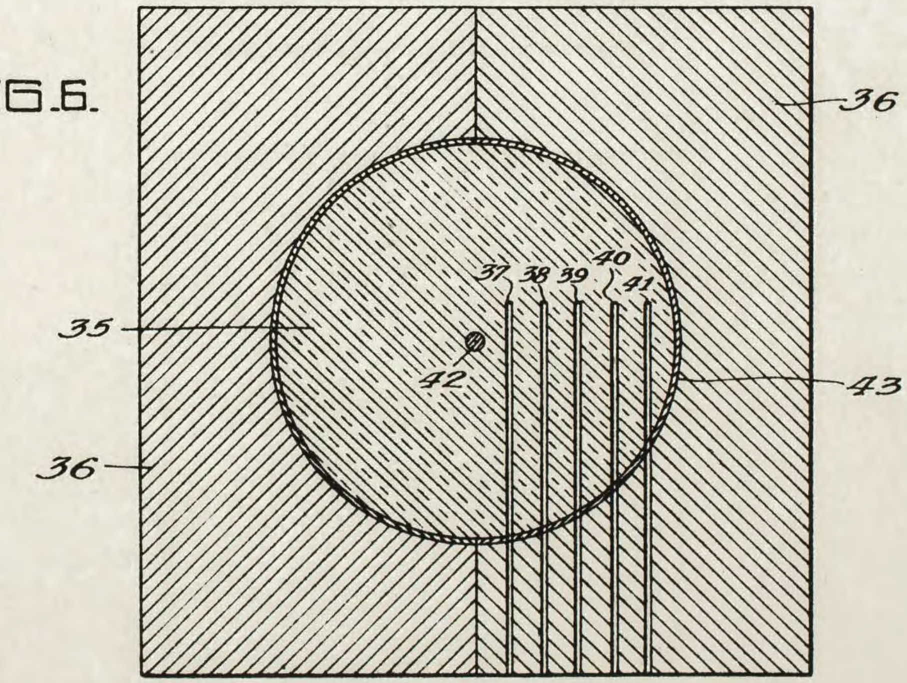


FIG.6.



2500 wds.
3 p. drawings