June 1, 1937. R. J. VAN DE GRAAFF 2,082,474

MATERIAL INSULATOR FOR USE IN VACUUM

Filed Dec. 6, 1934

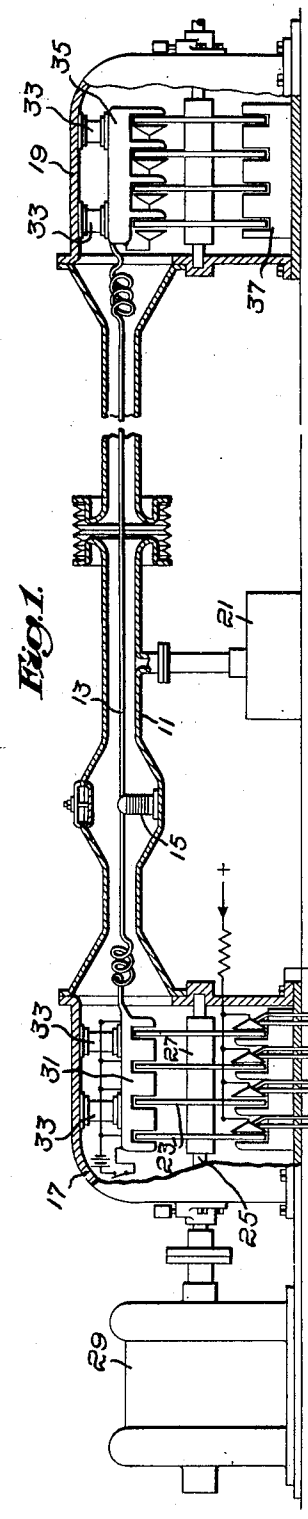

Fig. 1.

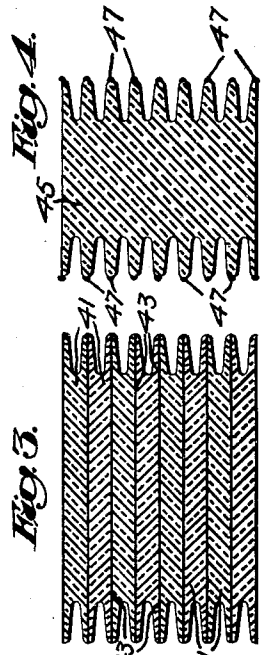

Fig. 4.

Fig. 3.

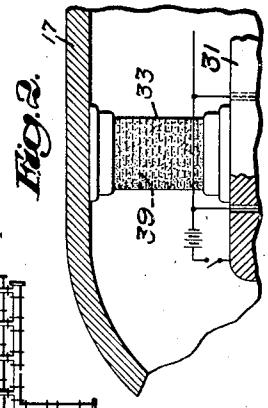

Fig. 2.

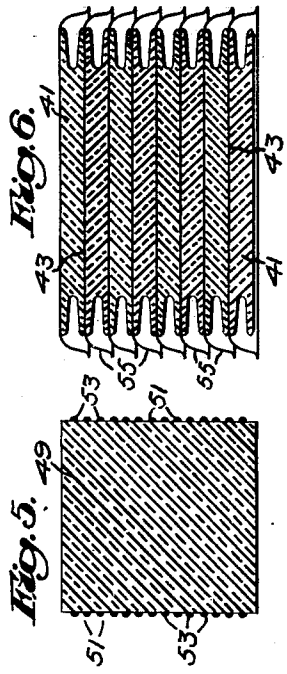

Fig. 6.

Fig. 5.

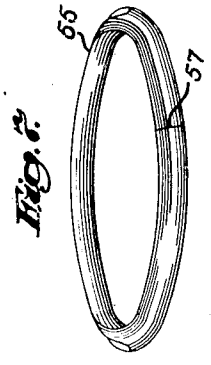

Fig. 7.

Inventor:
Robert J. Van de Graaff,
by Emery Booth Varney & Townsend
Attys

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MATERIAL INSULATOR FOR USE IN VACUUM

Robert J. Van de Graaff, Cambridge, Mass., assignor to Research Corporation, New York, N. Y., a corporation of New York

Application December 6, 1934, Serial No. 756,367

14 Claims. (Cl. 173—318)

This invention relates to insulating supports for bodies required to be maintained in vacuum at high potentials, more particularly though not exclusively in connection with direct current potentials, and has for its object the provision of a compact insulating support adapted to function effectively under the peculiar conditions arising when subjected to high electric fields in vacuum.

This application is a continuation in part of my prior application, Serial No. 620,964, filed July 5, 1932, now Patent No. 2,024,957, issued December 17, 1935, for Electrical transmission system.

When certain conditions of an electrode surface are realized, vacuum may be utilized to insulate extremely high voltage between electrode bodies with only a small physical separation. This necessitates, however, the supplementary use of material insulators in vacuum for their support.

Conditions surrounding material insulators immersed in vacuum differ in marked fundamental respects from those surrounding material insulators in other insulating media, such as air and oil. The voltage breakdown strength of solid insulation, such as quartz or porcelain, is ordinarily many times greater than the breakdown strength of a corresponding thickness of a fluid or gaseous insulating medium, such as air or oil. This is due to the relative ease with which ionization may be produced by strong electric fields in fluid or gaseous insulating medium. When the electric field intensity in such medium becomes sufficiently great, this ionization becomes cumulative and unstable and an arc or disrupting breakdown follows. Hence, the relatively low dielectric strength of the surrounding medium fundamentally limits the compactness of a solid insulator immersed in a material insulating medium, such as air or oil.

In high vacuum of the order here contemplated, as, for example, when the residual pressure of the evacuated space is approximately 10^{-5} millimeters of mercury or less, the solid insulator is surrounded by a medium whose dielectric strength is greater than its own, this being due to the fact that the residual gas molecules are too infrequent to permit cumulative ionization in the volume. Hence the immersion of suitable solid insulators, such as quartz, porcelain or the like, in a highly evacuated space removes an important limitation respecting compactness which attends the use of an insulator in other insulating media.

Accordingly, if those peculiar conditions pertaining to a vacuum are satisfied, insulators of suitably selected solid material immersed in a properly evacuated space may be utilized having great compactness and adapted to insulate electrode bodies subjected to abnormally high potentials, since the dielectric strength of the solid material itself may be more effectively utilized.

I have found it is not sufficient, however, merely to place insulating solids within a suitable vacuum in order to realize the full possibilities of their compactness and high voltage insulating strength. The condition of insulation in vacuum presents considerations not existing in the case of insulation in other media.

One condition which should be met for the effective use of the high dielectric strength of material insulators in vacuum is the distribution of total voltage along the insulator in such a way that the volume of the insulator is substantially uniformly stressed, as by the establishment of definite equipotential planes with provision for apportioning the total voltage between those planes in a predetermined manner.

Another condition in vacuum, and as I have found a more important one, is that the distribution of the total voltage along the insulator should be such that the surface as well as the volume of the material insulator should be substantially uniformly stressed.

In fact, the insulating condition of the surface of the insulator in vacuum becomes an important limiting factor, and the problem changes from one of seeking to strengthen the insulating effect of the medium surrounding the insulator to one of increasing the effectiveness of the insulator itself, and particularly increasing its effectiveness along the insulator surface.

I have found that, unless suitable provision is made, charges may be built up in an uncontrolled, random fashion on the surface of the insulator. These charges may be due to creepage along the insulator surface, to a non-homogeneous surface or volume, or to local bombardment by charged particles. Such charges being unable to escape from a surface of the insulator in vacuum, as they could with relative ease from such surface in air, tend to alter in an unpredetermined way the potential distribution along the insulator. Moreover, they may tend to effect an understressing of certain portions of the insulator at the expense of over-stressing the remaining portions. In short, the advantages of the vacuum insulation surrounding the material insulation may be defeated unless the growth of random surface charges over the insulator surface is reduced and controlled.

Furthermore, my investigations have shown

that break-down along insulator surfaces in vacuum may be precipitated by the bombardment of these surfaces by high speed particles originating from neighboring bodies. These impinging particles tend to cause the emission of secondary charged particles and may under certain conditions produce a cumulative interchange of charged particles, finally ending in a complete voltage breakdown.

Again these impinging particles may sufficiently accelerate the normal outgassing rate of the insulator so as to ruin at some local point the insulating properties of the vacuum. Such a local region would immediately ionize, upset the potential distribution along the insulator, and, if conditions are such that the effect becomes cumulative, would develop into complete breakdown.

The herein described invention has for its object the provision of material insulators for use in vacuum designed to meet the peculiar conditions, some of which have been heretofore referred to.

This and other objects of the invention will be best understood by reference to the following description when taken in connection with the accompanying illustration, while its scope will be more particularly pointed out in the appended claims.

In the drawing:

Fig. 1 shows, partly in section, a high voltage direct-current system in which the generation, transmission and utilization of the current is carried on in vacuum, affording one illustration of conditions under which material insulators are required to function in vacuum;

Fig. 2 is an enlarged detail showing an insulator employed for supporting a high voltage electrode body in the evacuated space of the system illustrated in Fig. 1;

Fig. 3 is a detail in cross-sectional elevation showing one method of constructing an insulating support designed to meet some of the conditions referred to;

Figs. 4 and 5 show further modified insulator constructions;

Fig. 6 shows an insulator similar to that shown in Fig. 3 but with the addition of provisions for shielding the insulating surface against breakdown due to impinging high speed particles; and

Fig. 7 is a detail in perspective showing the construction of the shield which is applied to the insulator of Fig. 6.

Referring to the drawing and particularly to Fig. 1, in order to present one illustrative instance of the use of material insulating supports immersed in a vacuum and the conditions under which they may be called on to function, there are shown the structural features of a system for the generation, transmission and utilization in vacuum of high voltage direct-current. This system is described in detail in my aforesaid prior application, Serial No. 620,964. For the purposes of describing the present invention the following explanation will suffice:

Referring to Fig. 1, the system there illustrated comprises an air-tight highly evacuated conduit 11, comprising herein a large cylindrical tube of conducting material, preferably of non-porous metal, such as rolled or drawn steel tubing, the inner walls of which have been subjected to an outgassing treatment to remove residual gases. Within the conducting tube 11 is an axial or central rod 13 of conductive material spaced from the conduit walls by insulator supports 15. The central conductor 13 is connected to a positive source of direct-current electro-motive force, the enveloping conducting tube 11 itself forming the grounded negative return conductor of the transmission line. The tubular conduit 11 at one end opens into an air-tight generator casing 17 and at the opposite end into a similar air-tight motor casing 19, so that the evacuated space extends continuously from and within the generator casing 17 through the tubular conduit 11, to and within the motor casing 19.

At suitable intervals lengthwise the conduit 11 there are provided vacuum pumps 21 having connection to the interior of the conduit and sufficient in number and of a type suitable to maintain within the conduit and within the casings 17 and 19 a high vacuum, as, for example, of the order represented by a pressure of 10^{-5} millimeters of mercury or less.

Within the casing 17 there is provided generating apparatus, herein of the direct-current electrostatic type, capable of generating high direct-current voltages, as, for example, of the order of 1,000,000 volts. Herein this comprises a plurality of non-conducting disks 23 mounted on a shaft 25 and spaced by sleeves 27, the shaft being driven by a source of external power, such as a turbine motor 29, to which the shaft passes through a vacuum-tight joint in the casing 17. Positive charges are placed on the lower portions of the disks 23 within the casing 17 by means of gas ionization, the provision for which is illustrated at the lower part of and below the casing 17 and the details of which are described in my aforesaid prior application. Positive charges applied to the lower portions of the disks 23 are removed or neutralized at the collector electrode 31, slotted to permit the passage of the disks, and suspended from the upper wall of the casing 17 by insulator columns 33 similar in construction to the insulator supports 15. The collector electrode 31 is connected directly to the central conductor 13 and the positive charges accumulating on the electrode are delivered to that conductor.

The motor contained in the motor casing 19 at the receiving end of the line is also herein of the electrostatic type, being of the same general construction as the generator but reversly arranged. That is to say, the gas ionizing units are located at the top of the disks for placing the positive charges on the upper portions thereof, the ionizing potential being afforded by the electrode body 35 connected to the positive conductor 13 and suspended from the upper wall of the casing 19 by insulators similar to the insulators 33, while the collector electrode 37 is positioned at and grounded to the bottom portion of the evacuated casing 19.

It will be seen that support of the conductor 13 within the conduit 11 and of the electrode bodies 31 and 35 within the casings 17 and 19 requires material insulators capable of functioning effectively in vacuum under abnormally high direct-current potentials.

One form of insulator usable for this purpose is illustrated in Fig. 2. This comprises a rod or column formed preferably of a material having a low vapor pressure and low outgassing tendency, such as quartz, glass, or material having the electrical characteristics of that known by the trade-name of "Pyrex". This insulator is provided with a series of spaced copper films 39 extending transversely the insulator and embedded therein to provide a controlled or predetermined voltage gradient.

Such insulators may be formed by depositing

a thin film of copper on one side of the thin plates of the insulating material employed, such plates, for example, being ¼ millimeter thick, piling up a stack of such plates to the desired height, and heating the stack slowly in vacuum to fuse the plates together without distortion. The cylindrical surface of the stack is then ground and polished, and a thin film of insulating substance such as quartz is deposited on the polished surface by evaporation in vacuum.

Since the insulating strength of "Pyrex" having a thickness of ¼ millimeter is about 80,000 volts, it is evident that the above procedure results in an insulator of great internal dielectric strength.

The effect of these conductive layers is to provide equipotential planes lengthwise the material insulator, breaking up the total voltage into a large number of small successive voltages in series. Since in the illustrative instance the insulator body is subject to the stress of a direct-current voltage without reversal of polarity, each conducting layer is maintained at its own substantially fixed potential and a predetermined current leakage takes place from one conducting layer to another through the volume of the intervening insulator, such leakage serving to maintain the predetermined apportionment of potential lengthwise the insulator, extending the stress substantially uniformly throughout its length, and establishing a substantially fixed potential gradient. Even if the insulating material is somewhat inhomogeneous in conductivity, the total leakage between conducting layers becomes an average over an area and this average would be closely the same for each element.

As heretofore stated, distribution of stress along the surface of the insulator is an important condition for effective insulation in vacuum, and preferred forms of construction are shown in Figs. 3, 4, 5, and 6, which are such as more completely to meet this condition either in the case of direct or alternating current voltages.

Referring to the insulation shown in Fig. 3, this comprises a series of transverse disk-like layers or plates 41 of insulating material built up into a column, the external edges of each plate being so shaped that when assembled they present an external corrugated periphery, thereby producing a longer leakage path along the insulating surface than through the volume. Between each insulating layer is a conducting equipotential plane 43. Such conducting plane may be produced by depositing upon one flat side of the insulating plate a thin film of copper, tungsten, or other conductive material, or even by painting over such side with a conductive fluid such as Roman gold or India ink and allowing the same to harden, the edge of the conductive film preferably extending to and being exposed on the external surface of the insulator.

For the insulating material in vacuum a non-porous substance, such as porcelain, glass, quartz or the like, having a low vapor pressure and a low outgassing tendency should preferably be employed. If substances having a relatively high vapor pressure or a relatively high outgassing tendency are employed, they should preferably have their exposed surfaces treated with a coating of a suitable substance, such as quartz, to reduce vapor pressure and outgassing tendency of their exposed surfaces.

The insulating plates, after being prepared in this manner, are assembled in column form and united in any suitable manner, as by fusing or baking, and when installed should be thoroughly outgassed.

In the case of the insulators constructed as shown in Fig. 3, the voltage is controlled by leakage through the volume of the insulator and by field currents or by surface leakage from the external edges of the equipotential planes. In this manner the total potential across the entire insulator is broken up into successive and preferably uniform sets, thereby subjecting the surface as well as the volume of the complete insulator to a relatively uniform electric stress. The effect of the exposed edge of each conducting layer is further to terminate at the first edge encountered any discharges which, when once started on the surface of the insulator, might otherwise tend to extend the whole length of the insulator.

As a specific illustration, a test made on an insulating element of the type shown in Fig. 3, immersed in a vacuum of the order herein referred to but in which element the distance between conducting rings was 6.7 millimeters, showed it capable of withstanding 130,000 volts between conducting rings. Allowing a factor of safety of two, by utilizing the methods disclosed herein, an insulator capable of supporting a body at 1,000,000 volts, even with this thickness of insulating plates, would require an overall length of onl about five inches.

The length and diameter of the insulating column and the number of equipotential planes will depend on the potential to be withstood. Increasing the number of equipotential planes serves to more effectively sub-divide and control the total potential across the insulator and would materially decrease the overall length required to insulate any given voltage.

In Fig. 4 there is illustrated a modified form of insulator construction where the insulating column 45 is a solid, uninterrupted unit but having corrugated edges similar to those of Fig. 3, such edges providing prolonged surface leakage paths. Herein, however, equipotential surfaces are controlled by the addition of a series of spaced narrow rings 47 of conducting material placed externally around the periphery and on the surface of the column, such rings being preferably located one at the tip of each corrugation. Each ring establishes a substantially uniform potential in its plane, the potential between successive conducting rings being controlled by surface leakage and by field currents between them. Such rings also serve further to suppress discharges which might otherwise tend to extend the whole length of the surface of the insulator.

An insulator functioning in a somewhat similar manner may also be had by the construction shown in Fig. 5. In this case the insulating column is also in the form of a solid unit 49 but may be cylindrical in form. On the surface of this column there is applied a coating of metallic conductive material, as by the deposition of a film of copper. The surface is then rendered alternately conducting and insulating by cutting away circular grooves in the surface of the coating, the cut penetrating to or into the insulating body beneath so as to leave exposed on the peripheral surface of the insulator rings 51 of insulating material alternating with rings 53 of conducting material, the latter establishing the desired equipotential planes.

The use of an unbroken column of insulating material, as in Figs. 4 and 5, represents a simplification which may be advantageously used, par-

ticularly in the case of insulating members of relatively small transverse dimensions. In such cases the influence of the equipotential ring need extend only a short distance into the interior of the column in order to maintain the equipotential surface in approximate coincidence with the plane of the ring.

In Fig. 6 is shown an insulator constructed substantially as in Fig. 3 but with the additional provision of shielding means for preventing the bombardment of the surface of the insulating material by high speed particles from an external source. Such shielding means are herein provided by means of a succession of thin metallic shields **55** encircling the insulator and extending in spaced relation from the outer periphery thereof. These are preferably in such position and relationship that each one slightly overlaps the next succeeding one, so that as viewed externally the insulator appears as a metallic unit. These shields may be constructed as shown in Fig. 7, comprising each a thin, slightly flared, skirt-like ring split at **57** so that, after the insulator plates have been assembled, it may be snapped into position and held by some suitable formation on the exterior walls thereof, as by a groove formed at the tip of each corrugation. When installed for use such insulator should be thoroughly outgassed, so that the outgassing tendency of the shields as well as that of the insulator is reduced to a minimum.

It will be seen that any impinging high speed particles strike on the metallic shields and would be prevented thereby from precipitating a breakdown which might occur more readily if they could strike the material insulator itself. These shields not only shield the insulating surface against such high speed particles, but also shield it from the influence of all potentials except the relatively low potential differences of the immediately adjacent conductive members.

In the case of an insulator shielded as in Fig. 6, the transverse conductive layers **43** may be omitted, the shielding rings themselves being relied on to control the equipotential surfaces.

It will be observed that through the provisions described in connection with Fig. 6 the insulator in vacuum may be subdivided electrically into a series of elements, each of which is designed to insulate a definite fraction of the total voltage, the material insulation of each element in respect to its surface as well as its volume being electrically aware only of the difference in potential which exists between its boundaries and not at all of the absolute potential which it may possess owing to its position in the series.

This reduces the problem of high voltage insulators in vacuum to a series of substantially similar low voltage insulators, each of which functions independently of its position in the potential scale, and makes possible not only an unusual degree of reliability and compactness, but also insulators capable of unprecedently high voltage strength.

While I have herein shown and described for purposes of illustration several modifications through which the principles of the invention may be carried out, it will be understood that, structurally speaking, the principles of the invention may be embodied in a great variety of forms, differing widely from those which are herein disclosed for illustrative purposes.

I claim:

1. A high voltage direct-current power system having high potential bodies supported in vacuum and means wholly immersed in vacuum for supporting the same, comprising insulators consisting of alternate transverse layers of insulating and conducting material and in which the total potential difference is divided between said conducting layers in accordance with a predetermined scheme by leakage between said conducting layers.

2. In a high voltage direct-current power system, a high potential body, an enclosure surrounding said body, means for maintaining a vacuum in said enclosure, and an insulator member wholly immersed in vacuum for supporting said body in said vacuum comprising a succession of relatively thin and alternately insulating and conductive portions arranged lengthwise said member and having a voltage gradient predetermined by leakage between said alternate conductive portions.

3. An insulating support for a high potential electrode body in vacuum, comprising an insulating body wholly immersed in vacuum and having a relatively low vapor pressure and outgassing tendency and presenting a longitudinal series of transversely arranged, spaced, conductive portions to provide a voltage gradient predetermined by leakage between said conductive portions.

4. An insulating support for a high potential electrode body in vacuum, comprising a body of insulating material wholly immersed in vacuum and having means for equalizing the distribution of stress lengthwise its surface comprising successive spaced conductive portions transverse the length of said support and exposed on the surface of said insulating material.

5. An insulating support for a high potential electrode body in vacuum, comprising a body of insulating material wholly immersed in vacuum and having means for equalizing distribution of stress along its surface and through its volume comprising successive spaced transverse layers of conductive material exposed on the surface of said insulator, thereby to establish equipotential planes at intervals along said support.

6. An insulating support for a high potential electrode body in vacuum, comprising a compact solid column of insulating material wholly immersed in vacuum, and means for preventing the formation of uncontrolled charge distributions over the surface of such support comprising a series of spaced conducting members presenting surfaces extending around the column on the surface thereof and sub-dividing the surface into successive areas alternately conducting and insulating.

7. An insulating support for high potential electrode bodies in vacuum, comprising a compact, solid column of insulating material wholly immersed in vacuum and means for preventing bombardment of the insulating surface by high speed particles comprising a series of spaced but overlapping conducting members contacting with and embracing the external surface of said insulating material.

8. An insulating support for a high potential electrode body in vacuum, comprising an insulating body wholly immersed in vacuum and means for distributing and equalizing the stress along the surface thereof through the allocation of voltage by field currents between successive regions on the surface, the said means comprising a series of transversely arranged, spaced, conductive portions on the surface of said sup-

port leaving intervening insulating areas separating said conductive portions.

9. An insulating support for a high potential electrode body in vacuum, comprising a body of insulating material wholly immersed in vacuum and means for distributing the stress lengthwise said support, comprising a succession of spaced conductive portions extending around said support on the surface thereof, the same establishing a succession of equipotential surfaces and sub-dividing the surface of said body into areas alternately conducting and insulating, the shortest surface leakage path over an insulating area from one conductive portion to another being greater than the distance between corresponding equalizing surfaces.

10. An insulating support for a high potential electrode body in vacuum, comprising a body of insulating material wholly immersed in vacuum and presenting on its external surface a series of transverse corrugations, and a succession of spaced conducting members extending around said support and sub-dividing the surface thereof into areas alternately conducting and insulating, said conducting members being positioned on said corrugations at substantially the region of maximum diameter.

11. An insulating support of column-like shape for spacing an electrode body in vacuum from a body having a high potential difference, said support being wholly immersed in vacuum and composed wholly of material having a relatively low vapor pressure and low outgassing tendency, and comprising further a series of transversely arranged, spaced, insulating portions with intermediate, spaced, conductive portions presenting exposed peripheral edges, the peripheral edges of the insulating portions extending beyond the edges of the conductive portions.

12. An insulating support of column-like shape for spacing an electrode body in vacuum from a body of high potential difference, said support comprising a body of insulating material and spaced conductive portions establishing equipotential planes along said support, said conductive portions presenting exposed surfaces around the periphery of said column, and means for preventing bombardment of the insulating surface by high speed electrical particles comprising a succession of spaced conductive shields.

13. An insulating support of column-like shape for spacing a body in vacuum from a body having a high potential difference, said support being wholly immersed in vacuum and composed mainly of insulating material but presenting on its surface a series of spaced conducting members extending around the support and sub-dividing the surface into areas which lengthwise the support are alternately conducting and insulating, said conducting members being so related that there is provided a voltage gradient pre-determined by leakage between successive conducting areas and there are established transverse, equipotential surfaces along said support.

14. An insulating support of column-like shape for spacing one body from another body, said two bodies having a high potential difference, said support comprising a compact solid body mainly of insulating material, means for establishing a high vacuum completely about said support, the separation of said bodies by said support at the point of attachment to said support being substantially the same as the length of said column, and means to equalize the distribution of stress lengthwise said insulating material.

ROBERT J. VAN DE GRAAFF.