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COMPLETE SPECIFICATION

Improvements in carrying out Nuclear Reactions

I, THEODORE VOLOCHINE, of Russian Nationality, of, 7, Avenue des Bleuets, Chevilly-Larue, France, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described, in and by the following statement:—

This invention relates to nuclear reaction processes of the fusion type, and more particularly to such reactions involving relatively light particles, including both nucleons and the lighter atomic nuclei, as the reagent particles.

A general object of the invention is to provide higher efficiency in fusion reactions and to permit of carrying out such reactions under practical conditions with a substantial release of useful power.

A fusion reaction generates an amount of energy proportional to the mass dissipated on fusion of the reacting particles, the released energy being given by Einstein's well-known equation $E=mc^2$, where E is the energy release, m the mass dissipated and c the velocity of light. By suitably selecting the reagent particles it has been known for many years that considerable energy releases may theoretically be obtained.

For example, a fusion reaction between a deuterium nucleus and a proton produces Helium—3 with a release of about 5,5 Mev. Reaction between a proton and a neutron yields a deuterium or heavy hydrogen nucleus with a liberation of about 2.2 Mev energy.

The above theoretical results are not generally attainable in practice, for a number of reasons. Thus in the above-mentioned deuterium-proton fusion reaction, since both reagent particles are positively charged, it is necessary to expand a certain amount of energy to overcome the resulting electrostatic repulsion effect. In the second above mentioned reaction involving proton-neutron fusion, the bombarding neutrons have to be retarded again at the expense of the net useful energy derivable from the process. In all cases moreover the probability ratio of effective encounters and consequent reactions between individual particles is extremely small at the temperatures that are practically feasible. Specific objects of this invention lie in overcoming the just-mentioned obstacles to the practical accomplishment of fusion processes and deriving higher outputs of energy at temperatures that are readily attainable in practice.

According to currently accepted theory, atomic nuclei comprise protons and neutrons, the two types of particles being collectively designated as nucleons. Each individual nucleon is characterized inter alia by its kinetic moment of rotation or spin, usually expressed in terms of the unit $h/2\pi$ where h is Planck's constant. Another factor characterizing every nucleon is the value of the magnetic moment, sometimes expressed in terms of a unit known as the nuclear magneton, and equal to

$$\frac{1}{2}\left(\frac{h}{2\pi}\,\frac{e}{mc}\right)$$

where e is the elementary charge of the electron, m the mass of the proton and c the velocity of light. The fact that nucleons possess a finite magnetic moment is a result of experience. As regards protons, the existence of a magnetic moment is readily explainable in view of the electric charge carried by the proton coupled with its spin. With regard to neutrons, however, such an explanation apparently fails since neutrons are not electronically charged particles. One convenient way of explaining this discrepancy is to assume that a neutron actually comprises two equal and opposite electrical charges spaced from one another. Whatever the theoretical explanation, however, the possession of a magnetic moment by the neutron is a universally accepted experimental finding.

In any nucleon the spin is a vector quantity and can conveniently be expressed as being equal to 1/2. The magnetic moment also is a vector quantity. In the proton the magnetic moment has been found equal to 2.79, being directed in the same sense as the spin vector.

In the neutron the magnetic moment is − 1.9 being directed in the opposite sense from the spin vector.

Extensive research conducted by the applicant in connection with the properties very briefly summarized above, has demonstrated the possibility of substantially increasing the probability figures for effective encounters and fusion reactions between nucleons, and between nucleons and atomic nuclei, by so arranging matters that the reagent particles are all presented to the reaction area under such conditions that their magnetic moments are so related as to contribute to bringing the particles towards one another, thereby substantially to increase the probability of an encounter between reagent particles.

When both reagent parts are assumed to be originally in a random condition, the result just specified according to this invention is brought about by subjecting both reagent parts to a polarizing magnetic field, so directed in each case as to bring the magnetic moments of the respective parts to the desired condition in which they aid the encounter and fusion of the individual particles.

The precise polarizing field to be applied to each reagent part, and the optimum paths to be imparted thereto, may according to an important feature of the invention be predetermined in accordance with the nature and characteristics of the particular nucleus to be produced in the reaction, specifically with the values of the magnetic moment and spin thereof, which in turn are known data or are easily determinable by known methods; thus the collective spin of a nucleus will equal the algebraic sum of the spin of the constituent nucleons in it, a similar rule applying to the resulting magnetic moment.

In accordance with a further feature of the invention, the polarizing field used and the path of travel imparted are so predetermined as to take into account certain stability conditions which the resulting nucleus must fulfill in order that it will be stable. This will be made clear at a later point. Moreover, in some cases where one of the reagent parts itself comprises a plurality of nucleons, the internal structure of such a reagent must also be taken into account in the predetermination of the polarizing field and path of travel to be applied to it.

It will be evident that in cases where one of the two reagent parts, either the bombarding or bombarded particles, already possesses an initial state such that its magnetic moment has a definite, and suitable, value, then the invention may contemplate applying a polarizing field only to the other reagent and such applied field will then be predetermined with due account to the existing magnetic state of the other reagent.

Any appropriate means may be used according to the invention to create the desired polarizing fields, including solenoids which the particles are made to traverse, magnetic fields to which stationary reagents may be subjected, and other equivalent means depending on the particular experimental conditions and on convenience.

Some exemplary forms of the invention will now be described by way of illustration but not of limitation, with reference to the accompanying drawings, wherein:—

Figs. 1 to 5 are explanatory vector diagrams serving to convey an understanding of the principles on which the invention is based;

Fig. 6 is a simplified and diagrammatic illustration of one exemplary form of apparatus by which the invention may be put into practice.

As already indicated above, any nucleon, whether a proton or a neutron, behaves as an elementary magnet characterizable by the direction, magnitude and sign of its magnetic moment. In the case of the proton, the South-North direction of the equivalent magnet is directed in the same sense as the spin vector. With the neutron on the other hand, it is the North-South direction of the equivalent magnet that is directed in the same sense as the spin vector. The representation here used involves representing a proton by (say) a full-line vector and a neutron by (say) a broken-line vector; in either case the direction of the vector arrow indicating the direction and sign of the spin vector of the nucleon. Hence, the direction of a full-line vector in this representation also indicates the South-North direction of the magnetic moment of the particle since this particle is a proton; and the direction of a broken-line vector indicates the North-South direction of the magnetic moment of the particle since the particle in this case is a neutron.

It should be understood that the vectorial representation used herein, as just defined, is convenient, but somewhat arbitrary, being based on the highly simplified hypothesis already outlined. Nevertheless it is found that the practical conclusions inferrable from such hypothesis and from the corresponding vectorial representation here given, is largely corroborated by experimental findings and is to a remarkable degree consistent with previously accepted data, and hence can be validly used herein as a means of describing the invention. While in some cases the values derived for the magnetic moments of some nuclei as inferred from this representation differ slightly from the corresponding values currently accepted as true, such discrepancies are slight and in any case they have no bearing on the actual operation of the method of the invention.

Referring to Fig. 1, this relates to a fusion reaction between a proton and a neutron to produce deuterium with the liberation of 2.2 Mev. The proton, here represented by the full-line vector is usually designated by the symbol

$^{1}_{1}H$ and is characterized by spin $\frac{1}{2}$ and magnetic moment 2.79. The neutron (broken-line vector has the symbol $^{1}_{0}n$ (hereinafter written n for simplicity) and has a spin $\frac{1}{2}$ and magnetic moment -1.9. The resulting deuterium particle has the symbol $^{2}_{1}H$ and is known to possess spin 1 and magnetic moment 0.9. In accordance with the invention, at least one of the poles of one of the particles is brought adjacent to the pole of opposite denomination of the other particle. As will be apparent from Fig. 1, optimum reaction efficiency will be obtained if the reagent neutron and proton are brought to a relative position such that their representative vectors are parallel and directed in the same sense. In this condition the spins are parallel and the magnetic moments are anti-parallel. The resulting spin of the pair of nucleons then is $\frac{1}{2}+\frac{1}{2}=1$, and the resulting magnetic moment is $2.79+(-1.9)=0.89$.

It is to be noted that the same deuterium-forming reaction may apparently be brought about by placing the neutron and the proton in the presence of one another in accordance with either of Figs. 2*a* and 2*b*, since in either case a North magnetic pole of one particle is adjacent to a South pole of the other. In this case the resulting spin of the nucleus produced by fusion would be $\frac{1}{2}+(-\frac{1}{2})=0$ and the resulting magnetic moment would be $2.79-(-1.9)=4.69$.

Now the spin and magnetic moment of the deuterium neucleus as obtained by direct methods have the values 1 and 0.90 respectively (as mentioned above), and it is seen that these values are extremely close to the values of 1 and 0.89 obtained in the preceding paragraph from a consideration of the vector diagram of Fig. 1. However, no deuterium nuclei have ever been observed having a spin and magnetic moment values approaching 0 and 4.69 as found in Figs 2*a* and 2*b*. This shows that any deuterium nucleus that might be obtained in the manner shown in these two figures is unstable. That this must be so is rather evident since the bonding energy of a deuterium nucleus such as the one in Fig. 2*a* or 2*b*, would necessarily be less than that of a deuterium nucleus such as that in Fig. 1, wherein there are two magnetic attraction bonds as against the single, bond in either of Figs. 2*a* or 2*b*. It is Fig. 1 therefore, that must represent the stable state of the deuterium nucleus whereas Figs. 2*a* and 2*b* represent excited states which may possibly occur but are generally unstable and tend to revert to the more stable state.

Fig. 1, therefore, in addition to showing how the particles are to be polarized further indicates that in accordance with the invention the proper way of bringing the particles together is by conducting them towards one another in a direction normal to the common direction of their spin and magnetic moment.

By incorporating a neutron into the deuterium nucleus, tritium is formed by the fusion reaction:—

$$^{2}_{1}H+n=^{3}_{1}H$$

the spin of the resulting particle being $\frac{1}{2}$, its magnetic moment 2.9 and the released energy 6.26 Mev. Fig. 3 illustrates how this nucleus can be formed by polarizing the reagents deuterium and neutron, and directing the additional neutron towards the deuterium along a path of travel parallel to the common direction of spin and magnetic moment.

In such conditions the values of spin and magnetic moment as resulting from the vector diagram of Fig. 3 are: Spin $=0+\frac{1}{2}=\frac{1}{2}$, and magnetic moment

$$=2.79-(-1.9)+(-1.9)=2.79.$$

This set of values corresponds exactly with the conventional values for the spin and magnetic moment of tritium as given above, hence showing that the conditions indicated in Fig. 3 will effectively lead to the occurrence of a fusion reaction and the formation of stable tritium.

Figs. 3*a* and 3*b* show other conceivable ways of forming a tritium nucleus. In these figures an incident neutron is assumed to be so polarized that its spin is in the same sense as that of the deuterium nucleus and said neutron is conducted along a direction perpendicular to the common direction of the spins and magnetic moments in Fig. 3*a* and parallel thereto as in Fig. 3*b*. For both these cases the resulting spin would be $\frac{1}{2}+\frac{1}{2}+\frac{1}{2}=3/2$ and the resulting magnetic moment would be $2.79+(-1.9)+(-1.9)=-1.01$. These values do not correspond to the known values of tritium's spin and magnetic moment, and the conditions illustrated in Figs. 3*a* and 3*b* are, therefore, according to the invention, to be discarded.

In accordance with known principles of nuclear mechanics it is to be presumed that two particles having identical values of spin and magnetic moment, such as the two neutrons involved in the instance presently being described, are unable to coexist unchanged and hence, the neutron will be converted into a proton and a pair of oppositely charged electrons $\beta^{+}+\beta^{-}$ with negative electron β^{-} being discharged. This would result in the formation of helium $^{3}_{2}He$ having spin $\frac{1}{2}$ and magnetic moment -1.9 (the actual magnetic moment of helium is -2.1), as shown in Fig. 4. The released energy in this case is 5.5 Mev.

Fig. 4 therefore indicates how there may be produced helium 3 $^{3}_{2}He$ by combining deuterium and a proton. The diagram indicates in accordance with the invention that in this case the reagents should be so polarized that their spin vectors will be opposed and that they should be conducted toward each other in a direction parallel to the common direction of spin and magnetic moment so that the bombarding proton will be able to combine with the deuterium neutron as shown. It will be understood of course that sufficient energy must be imparted to the incident proton to overcome the electrostatic repulsion between it and the deuterium proton.

From the helium 3 nucleus shown in Fig. 4 helium 4 $^{4}_{2}He$ may be formed by addition thereto of a further neutron, the energy release being 20.5 Mev. The process in this case will be as follows, it being noted that the resulting magnetic moment of helium 3 corresponds to the magnetic moment of the neutron. The bombarding neutrons are so polarized and accelerated in such a direction that they will combine with the helium 3 nucleus in the manner illustrated in Fig. 5 to yield a resulting nucleus having a spin equal to 1(i.e. $\frac{1}{2}+\frac{1}{2}$) and a resulting magnetic moment equal to -3.8. However, it is known from the other sources that helium $^{4}_{2}He$ actually possesses zero spin and zero magnetic moment. This indicates that the hypothetical nucleus shown in Fig. 5 is unstable, and will of its own accord be converted into the alternative form of nucleus illustrated by the diagram of 5*a*, which is seen to possess the characteristics of zero spin and zero magnetic moment as displayed by stable helium 4 nuclei in nature.

The process of the invention is of course applicable to elements having atomic numbers higher than the elements mentioned so far herein. Thus, as an example, the invention will permit deriving from lithium 6, through fusion of a proton therewith, helium 3 and helium 4 in accordance with the equation:

$$^{6}_{3}Li+{}^{1}_{1}H={}^{4}_{2}He+{}^{3}_{2}He+Mev.$$

The chief advantage of such a reaction will lie in the fact that it can provide $^{3}_{2}He$ which in turn can serve as a starting point for the formation of $^{4}_{2}He$ which, as mentioned above, is accompanied by a liberation of 20.5 Mev.

As will appear from the foregoing, both protons and/or neutrons may be used as the bombarding particles. In the present state of nuclear engineering, neutrons would usually be employed as the bombarding particles; this presents the important advantage that, since neutrons are electrically neutral, they can be brought into substantial contact with the bombarded particles without generating electrostatic repulsion forces. However, in view of the limited lifetime of neutrons, which is of the order of 10 minutes, it will generally be necessary to use neutrons in the nascent state.

Any suitable neutron source may be used. Thus the source of nascent neutrons may be provided by bombarding beryllium (glucinium) atoms with radiation from a radioactive source such as radium and/or polonium compounds or possibly artificial radio-elements. As an example of one form of neutron source successfully usable according to the invention, there may be provided an enclosure containing beryllium and radio-active material, said enclosure communicating with the reactor chamber containing the bombarded material by way of an opening sealed with a wall permeable to neutrons, such as a thin foil of aluminium or other suitable metal, with a movable shutter comprising lead or other impermeable material associated with said opening. The resulting assembly will be associated with appropriate polarizing means according to the invention, as further described hereafter.

In order to increase the cross section area of the neutrons, in accordance with known nuclear techniques, the neutrons are preferably retarded. This may be done mechanically by means of conventional moderator, and/or by operating at a suitably low temperature. Thus, a moderator substance such as paraffin, liquid helium, heavy water, or the like may be interposed on the path of the neutrons, and suitable cooling means may simultaneously be used.

Fig. 6 diagrammatically illustrates apparatus for carrying out the process of the invention and comprising a source of bombarding particles 1, e.g. a neutron source, having a window 2 and slidable lead shutter 3 associated with it as described above, a moderator element 4 such as a block of paraffin provided with cooling means, not illustrated, as also mentioned above, an enclosure 5 containing the source or body of bombarded particles, a reactor chamber 6, and means associated with the reactor chamber for utilizing the output energy developed, e.g. a fluid circulating device 7 illustrated as a jacket surrounding the reactor chamber; there is further shown a conduit 8 connecting the enclosure 5 with the chamber 6 and magnetic polarizing means associated with said conduit and shown in the form of a winding 9 surrounding the conduit, with reverser means 10 connected in the supply circuit of the winding. Similarly a conduit 11 connects enclosures 1 and 6 and magnetic polarizing means are associated with the conduit 11 for creating a polarizing field selectively in axial and transverse directions, which means include a winding 12 creating an axial field and magnetic poles 13 for creating the transverse field; each of said means having a reversing device, such as the reverser 14 (shown only in connection with the axial field winding 12) connected in its supply circuit.

In addition, the assembly including the source 5 of bombarded particles and the channel 9 as well as the associated polarizing winding 9, is preferably mounted on a pivotal support relatively to the reactor chamber 6, so as to be selectively positionable in either the position shown in full lines or in a position at right angles thereto as shown in dotted lines. Such an arrangement will make it possible to produce any of the sets of operating conditions mentioned with reference to Figs. 1—5.

It will be understood by those familiar with the art of nuclear engineering that the invention may be embodied in many other ways than those specifically described herein, in accordance with a large number of nuclear fusion reactions involving many different combinations between elementary particles and/or nuclei. Also, the apparatus schematically illustrated in Fig. 6 is exemplary only since various technically equivalent forms may readily be devised.

It is to be understood that in the ensuing claims, the word "particle" is used to designate both elementary particles such as nucleons, and atomic nuclei or composite particles such as deuterium nuclei, tritium nuclei, helium nuclei, and other atomic nuclei.

What I claim is:—

1. A system for producing usable nuclear power, which comprises respective sources of neutrons and second reagent particles so selected that a fusion-type reaction between them will result in the formation of at least one resulting particle with a mass defect and consequent liberation of energy, first means for magnetically polarising said neutrons and second particles and second means for leading along paths these particles towards each other in a reaction zone, the directions of said polarization and of said paths being so predetermined in correlation with one another that said particles tend to assume relative positions within said zone such that the magnetic moments thereof will set up attractive forces between said neutrons and second particles and that the vector sums of the spins and the vector sums of the magnetic moments of said particles in the reaction zones respectively approximate in value the spin and magnetic moment of a substantially stable one of said resulting particles.

2. A system for producing usable nuclear power, which comprises respective sources of neutrons and second reagent particles so selected that a fusion-type reaction between them will result in the formation of at least one resulting particle with a mass defect and corresponding liberation of energy, first means for magnetically polarizing said particles and second means for leading along paths these particles towards each other in a reaction zone, the directions of said polarization and of said paths being so selected in correlation with one another that said particles tend to assume relative positions within said zone such that the magnetic moments thereof set up a maximum attractive force between said neutrons and second particles to ensure that said reaction will result in the formation of a substantially stable one of said resulting particles.

3. A system according to Claim 1 or 2, wherein said neutrons and second particles are magnetically polarized in a common direction.

4. A system according to Claim 3, wherein said neutrons and second particles are polarized with similar signs.

5. A system according to Claim 3, wherein said neutrons and second particles are polarized with opposite signs.

6. A system according to Claim 3, 4 or 5, wherein the paths of motion due to said leading means are parallel to said common direction of polarization.

7. A system according to Claim 3, 4 or 5, wherein the paths of motion due to said leading means are normal to said common direction.

8. A system according to Claim 1 or 2, as appended on Claims 5 and 7, wherein said second particles are protons, said resulting particle is deuterium and said liberated energy is 2.2 Mev.

9. A system according to Claim 1 or 2 as appended on Claims 5 and 6, wherein said second particles are deuterium, said resulting particle is tritium and said liberated energy is 6.3 Mev.

10. A system according to Claim 1 or 2 as appended on Claim 4 and 6 wherein said second particles are Helium—3, said resulting particle is Helium—4 and said liberated energy is 20.5 Mev.

11. A system according to any preceding claim, wherein the described process is carried out under substantially ordinary temperature conditions.

12. A system according to any preceding claim which includes means for retarding the velocity of said neutrons.

13, A system according to Claim 12, wherein said retarding means include a moderator substance.

14. A system according to Claim 12 or 13, wherein said retarding means include cooling means.

15. A system according to any preceding claim which comprises first and second channels respectively connecting said reaction zone with said first and said second source, and means for selectively altering the angular relationship between said channels from a

parallel to a perpendicular relationship and vice versa.

16. A system according to Claim 15, wherein said last mentioned means comprise a movable mounting system for selectively altering the orientation of one of said channels between an orientation where it is aligned with and an orientation where it is normal to, the other channel.

17. A system according to Claim 6, wherein the polarizing means comprise a first magnetic field-creating device associated with said one channel for creating a field directed axially of the latter, a second and third magnetic field-creating devices associated with said other channel for creating respective fields directed axially and transversely of the latter, supply means for energising said first magnetic means and a selected one of said second and third magnetic means, and reverser means connected in said supply means for selectively reversing the signs of said fields.

18. A system according to any of Claims 15 to 17 which includes a movable shutter device interposable in one of said channels and impermeable to the particles from the related source.

19. A system for producing usable nuclear power, substantially as described with reference to Figures 1 to 5, and substantially as illustrated in Figure 6, of the accompanying diagrammatic drawings.

20. A method of producing usable nuclear power substantially as described in the specification.

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795,596 COMPLETE SPECIFICATION
1 SHEET
This drawing is a reproduction of the Original on a reduced scale.

FIG.1

FIG.2a

FIG.2b

FIG.3

FIG.3a

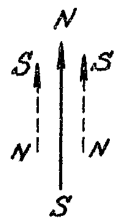

FIG.3b

FIG.4

FIG.5a

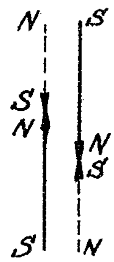

FIG.5

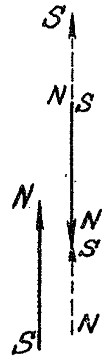

FIG.6