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Accessory Publication

The Neutron - The Curie Family's Legacy

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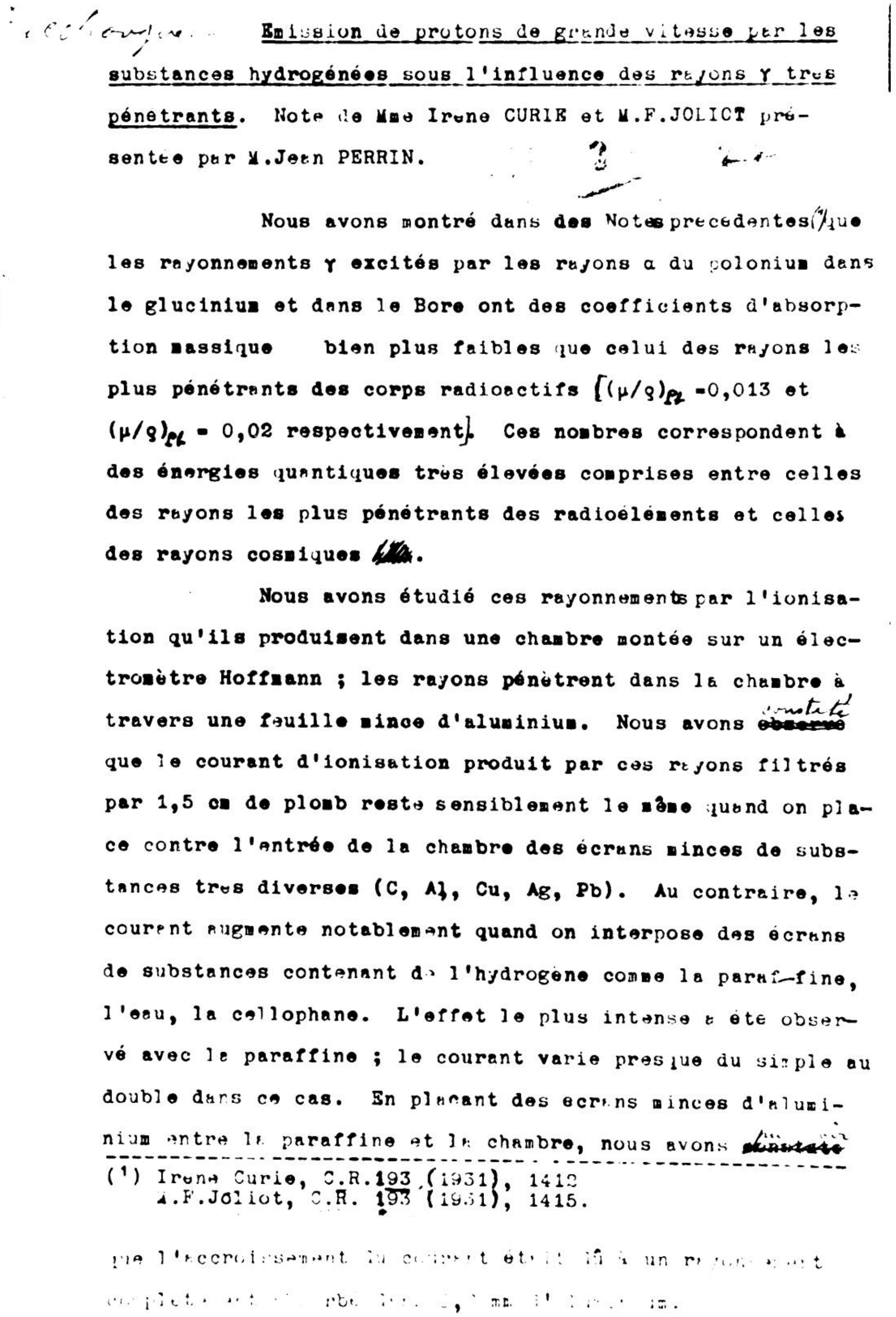
Figure 1 Centre piece of the Exhibition at the Wellcome Hall of the Royal Society, London Conversatione 8 May and 24 June 1982 to commemorate the 50th Anniversary of the neutron's discovery by Sir James Chadwick.



Emission de protons de grande vitesse par les substances hydrogénées sous l'influence des rayons γ très pénetrants. Note de Mme Irene CURIE et M.F.JOLIOT présentée par M.Jean PERRIN.

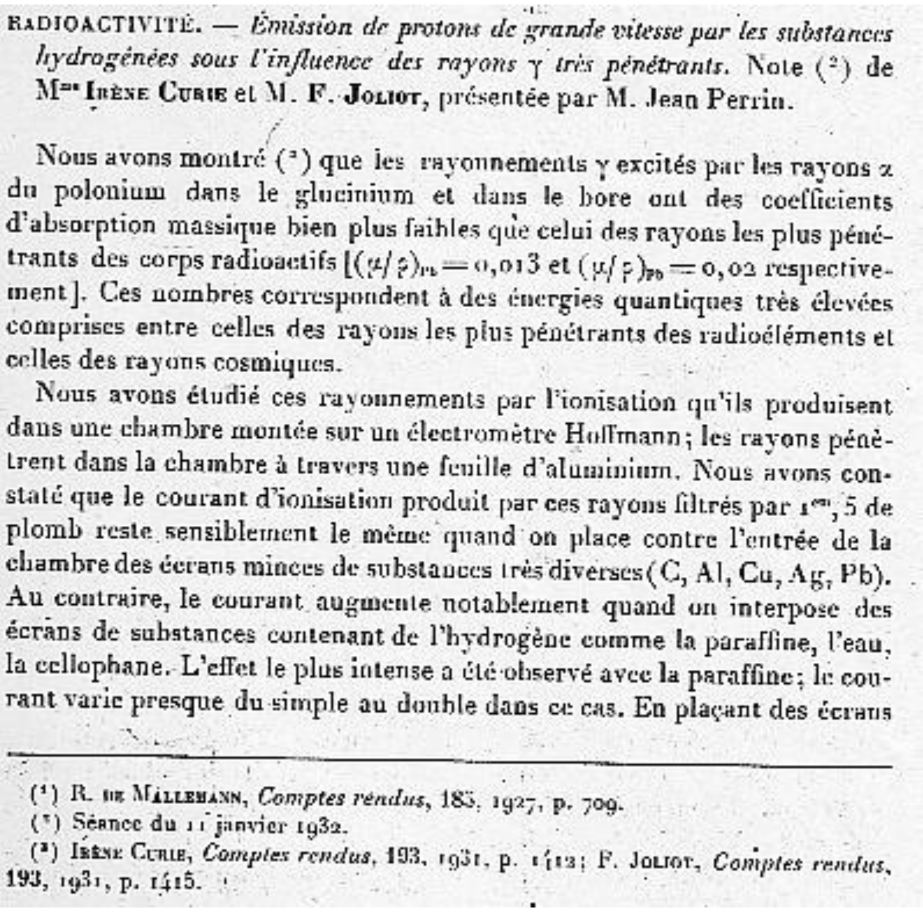
Nous avons montré dans des Notes precedentes(¹) que les rayonnements γ excités par les rayons α du polonium dans le glucinium et dans le Bore ont des coefficients d'absorption massique bien plus faibles que celui des rayons les plus pénétrants des corps radioactifs $[(\mu/\rho)_{Pb} = 0{,}013$ et $(\mu/\rho)_{Pb} = 0{,}02$ respectivement$]$. Ces nombres correspondent à des énergies quantiques très élevées comprises entre celles des rayons les plus pénétrants des radioéléments et celles des rayons cosmiques.

Nous avons étudié ces rayonnements par l'ionisation qu'ils produisent dans une chambre montée sur un électromètre Hoffmann ; les rayons pénètrent dans la chambre à travers une feuille mince d'aluminium. Nous avons ~~observé~~ constaté que le courant d'ionisation produit par ces rayons filtrés par 1,5 cm de plomb reste sensiblement le même quand on place contre l'entrée de la chambre des écrans minces de substances très diverses (C, Al, Cu, Ag, Pb). Au contraire, le courant augmente notablement quand on interpose des écrans de substances contenant de l'hydrogène comme la paraffine, l'eau, la cellophane. L'effet le plus intense a été observé avec la paraffine ; le courant varie presque du simple au double dans ce cas. En plaçant des ecrans minces d'aluminium entre la paraffine et la chambre, nous avons ~~constaté~~

(¹) Irene Curie, C.R. 193 (1931), 1412
M.F.Joliot, C.R. 193 (1931), 1415.

que l'accroissement du courant était dû à un rayonnement complètement absorbé [illegible] [illegible], [illegible] mm d'aluminium.

Figure 2 The first page of the Joliot-Curie manuscript to *Comptes rendus* February 1932



RADIOACTIVITÉ. — *Émission de protons de grande vitesse par les substances hydrogénées sous l'influence des rayons γ très pénétrants.* Note (2) de Mme **Irène Curie** et M. **F. Joliot**, présentée par M. Jean Perrin.

Nous avons montré (3) que les rayonnements γ excités par les rayons α du polonium dans le glucinium et dans le bore ont des coefficients d'absorption massique bien plus faibles que celui des rayons les plus pénétrants des corps radioactifs $[(\mu/\rho)_{Pb} = 0,013$ et $(\mu/\rho)_{Pb} = 0,02$ respectivement]. Ces nombres correspondent à des énergies quantiques très élevées comprises entre celles des rayons les plus pénétrants des radioéléments et celles des rayons cosmiques.

Nous avons étudié ces rayonnements par l'ionisation qu'ils produisent dans une chambre montée sur un électromètre Hoffmann; les rayons pénètrent dans la chambre à travers une feuille d'aluminium. Nous avons constaté que le courant d'ionisation produit par ces rayons filtrés par $1^{cm},5$ de plomb reste sensiblement le même quand on place contre l'entrée de la chambre des écrans minces de substances très diverses (C, Al, Cu, Ag, Pb). Au contraire, le courant augmente notablement quand on interpose des écrans de substances contenant de l'hydrogène comme la paraffine, l'eau, la cellophane. L'effet le plus intense a été observé avec la paraffine; le courant varie presque du simple au double dans ce cas. En plaçant des écrans

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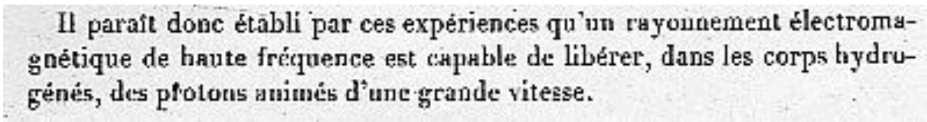
(1) R. de Mallemann, *Comptes rendus*, 185, 1927, p. 709.

(2) Séance du 11 janvier 1932.

(3) Irène Curie, *Comptes rendus*, 193, 1931, p. 1412; F. Joliot, *Comptes rendus*, 193, 1931, p. 1415.

………..



Il paraît donc établi par ces expériences qu'un rayonnement électromagnétique de haute fréquence est capable de libérer, dans les corps hydrogénés, des protons animés d'une grande vitesse.

Figure 3 Extract from the published paper *Comptes rendus* February 1932

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Letters to the Editor

[*The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of* Nature. *No notice is taken of anonymous communications.*]

Possible Existence of a Neutron

It has been shown by Bothe and others that beryllium when bombarded by α-particles of polonium emits a radiation of great penetrating power, which has an absorption coefficient in lead of about 0·3 (cm.)$^{-1}$. Recently Mme. Curie-Joliot and M. Joliot found, when measuring the ionisation produced by this beryllium radiation in a vessel with a thin window, that the ionisation increased when matter containing hydrogen was placed in front of the window. The effect appeared to be due to the ejection of protons with velocities up to a maximum of nearly 3×10^9 cm. per sec. They suggested that the transference of energy to the proton was by a process similar to the Compton effect, and estimated that the beryllium radiation had a quantum energy of 50×10^6 electron volts.

I have made some experiments using the valve counter to examine the properties of this radiation excited in beryllium. The valve counter consists of a small ionisation chamber connected to an amplifier, and the sudden production of ions by the entry of a particle, such as a proton or α-particle, is recorded by the deflexion of an oscillograph. These experiments have shown that the radiation ejects particles from hydrogen, helium, lithium, beryllium, carbon, air, and argon. The particles ejected from hydrogen behave, as regards range and ionising power, like protons with speeds up to about $3{\cdot}2 \times 10^9$ cm. per sec. The particles from the other elements have a large ionising power, and appear to be in each case recoil atoms of the elements.

If we ascribe the ejection of the proton to a Compton recoil from a quantum of 52×10^6 electron volts, then the nitrogen recoil atom arising by a similar process should have an energy not greater than about 400,000 volts, should produce not more than about 10,000 ions, and have a range in air at N.T.P. of about 1·3 mm. Actually, some of the recoil atoms in nitrogen produce at least 30,000 ions. In collaboration with Dr. Feather, I have observed the recoil atoms in an expansion chamber, and their range, estimated visually, was sometimes as much as 3 mm. at N.T.P.

These results, and others I have obtained in the course of the work, are very difficult to explain on the assumption that the radiation from beryllium is a quantum radiation, if energy and momentum are to be conserved in the collisions. The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons. The capture of the α-particle by the Be^9 nucleus may be supposed to result in the formation of a C^{12} nucleus and the emission of the neutron. From the energy relations of this process the velocity of the neutron emitted in the forward direction may well be about 3×10^9 cm. per sec. The collisions of this neutron with the atoms through which it passes give rise to the recoil atoms, and the observed energies of the recoil atoms are in fair agreement with this view. Moreover, I have observed that the protons ejected from hydrogen by the radiation emitted in the opposite direction to that of the exciting α-particle appear to have a much smaller range than those ejected by the forward radiation. This again receives a simple explanation on the neutron hypothesis.

If it be supposed that the radiation consists of quanta, then the capture of the α-particle by the Be^9 nucleus will form a C^{13} nucleus. The mass defect of C^{13} is known with sufficient accuracy to show that the energy of the quantum emitted in this process cannot be greater than about 14×10^6 volts. It is difficult to make such a quantum responsible for the effects observed.

It is to be expected that many of the effects of a neutron in passing through matter should resemble those of a quantum of high energy, and it is not easy to reach the final decision between the two hypotheses. Up to the present, all the evidence is in favour of the neutron, while the quantum hypothesis can only be upheld if the conservation of energy and momentum be relinquished at some point.

J. Chadwick.

Cavendish Laboratory,
Cambridge, Feb. 17.

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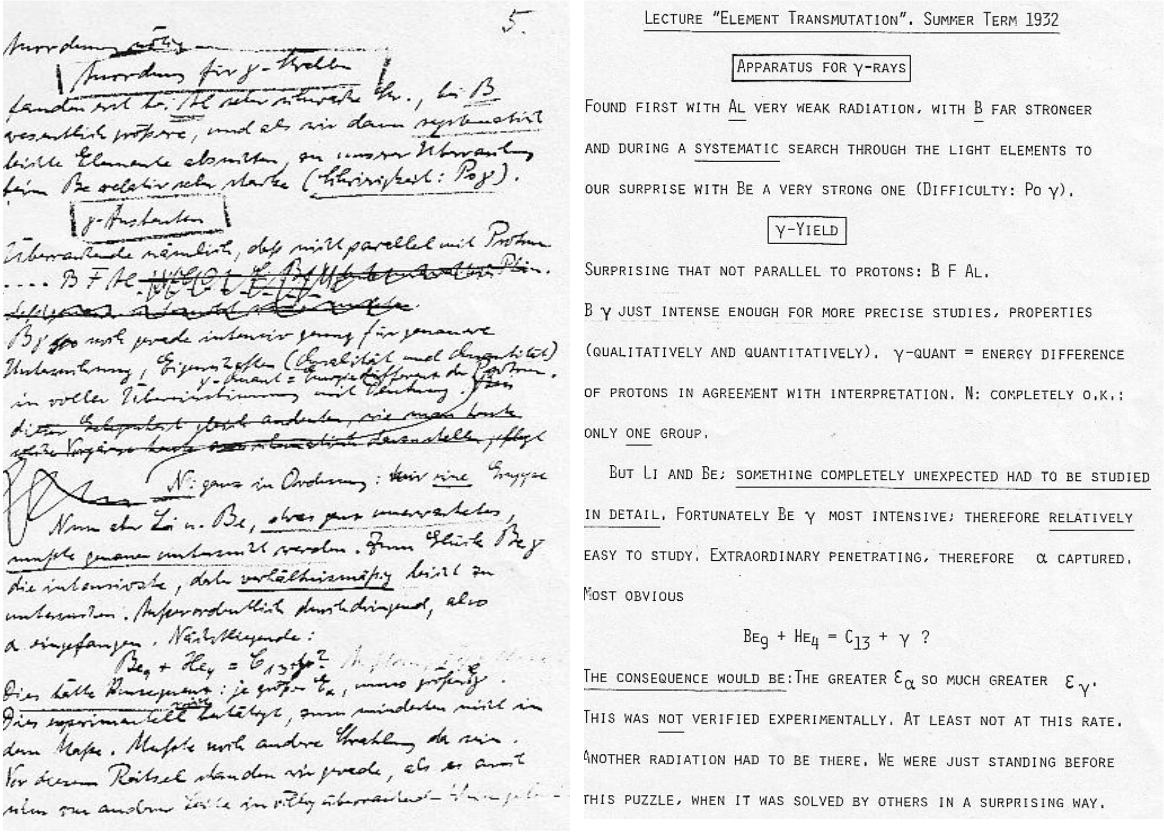
Figure 4 Chadwick’s announcement of his discovery of the neutron in *Nature* 1932



Lecture "Element Transmutation". Summer Term 1932

Apparatus for γ-rays

Found first with Al very weak radiation, with B far stronger and during a systematic search through the light elements to our surprise with Be a very strong one (Difficulty: Po γ).

γ-Yield

Surprising that not parallel to protons: B F Al.

B γ just intense enough for more precise studies, properties (qualitatively and quantitatively). γ-quant = energy difference of protons in agreement with interpretation. N: completely o.k.: only one group.

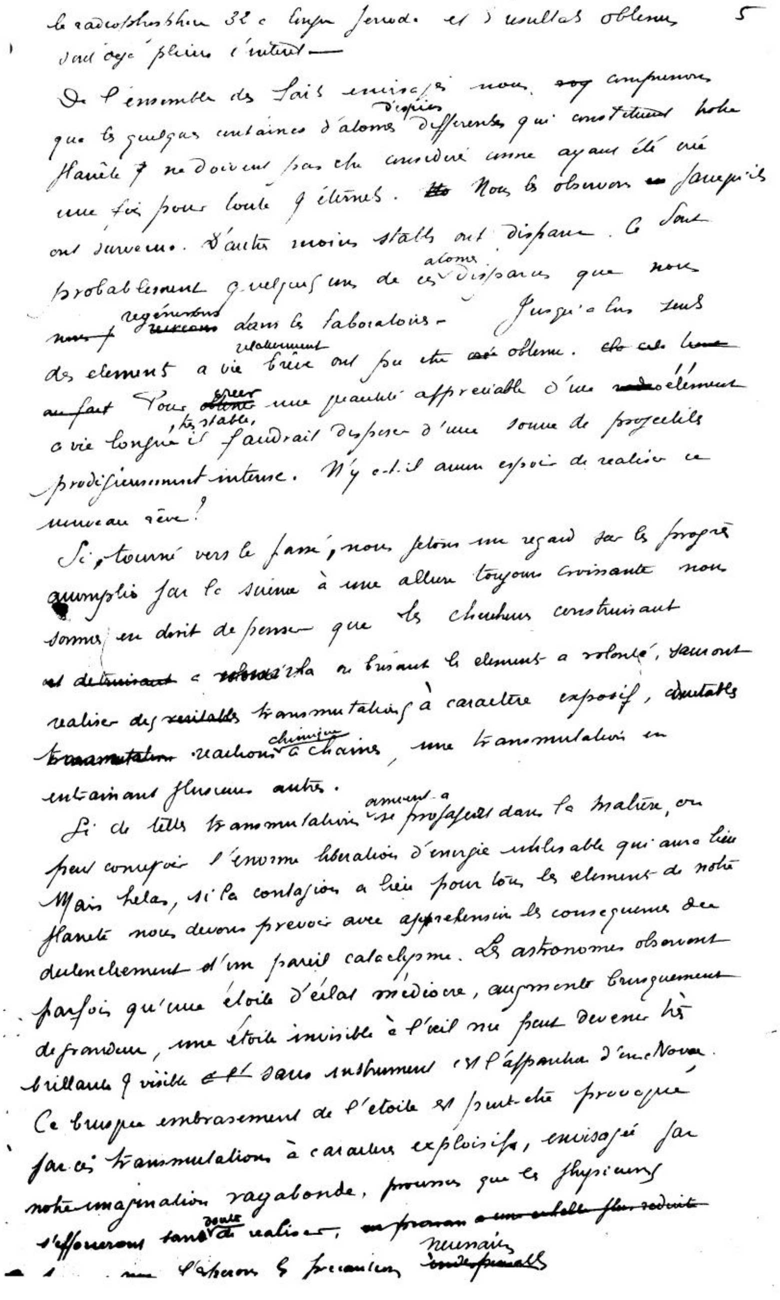
But Li and Be; something completely unexpected had to be studied in detail. Fortunately Be γ most intensive; therefore relatively easy to study. Extraordinary penetrating, therefore α captured. Most obvious

$$Be_9 + He_4 = C_{13} + \gamma \ ?$$

The consequence would be: The greater ε_α so much greater ε_γ.

This was not verified experimentally. At least not at this rate. Another radiation had to be there. We were just standing before this puzzle, when it was solved by others in a surprising way.

Figure 5 An extract of Professor Bothe’s lecture notes from the summer of 1932, and the translation provided.



le radiophosphore 32 à longue période et les résultats obtenus 5
sont déjà pleins d'intérêt —
De l'ensemble des faits envisagés nous ~~sog~~ comprenons
que les quelques centaines d'atomes espèces différents qui constituent notre
planète ne doivent pas être considérés comme ayant été créés
une fois pour toutes éternels. ~~Ils~~ Nous les observons ~~en~~ parce qu'ils
ont survécu. D'autres moins stables ont disparu. Ce sont
probablement quelques uns de ces atomes disparus que nous
~~nous f~~ régénérons ~~recréons~~ dans les laboratoires. Jusqu'à lors seuls
des éléments à vie relativement brève ont pu être ~~créés~~ obtenus. ~~Ils cela bien~~
~~au fait~~ Pour ~~obtenir~~ créer une quantité appréciable d'un ~~radio~~élément
à vie longue, très stable, il faudrait disposer d'une source de projectiles
prodigieusement intense. N'y a-t-il aucun espoir de réaliser ce
nouveau rêve ?

Si, tournés vers le passé, nous jetons un regard sur les progrès
accomplis par la science à une allure toujours croissante nous
sommes en droit de penser que les chercheurs construisant
~~ou détruisant~~ à ~~volonté~~ ou brisant les éléments à volonté, sauront
réaliser des ~~véritables~~ transmutations à caractère explosif, véritables
~~transmutation~~ réactions chimiques à chaînes, une transmutation en
entraînant plusieurs autres.

Si de telles transmutations arrivent à se propager dans la matière, on
peut concevoir l'énorme libération d'énergie utilisable qui aura lieu
Mais hélas, si la contagion a lieu pour tous les éléments de notre
planète nous devons prévoir avec appréhension les conséquences du
déclenchement d'un pareil cataclysme. Les astronomes observent
parfois qu'une étoile d'éclat médiocre, augmente brusquement
de grandeur, une étoile invisible à l'œil nu peut devenir très
brillante et visible ~~et~~ sans instrument c'est l'apparition d'une Nova.
Ce brusque embrasement de l'étoile est peut-être provoqué
par ces transmutations à caractère explosifs, envisagé par
notre imagination vagabonde, processus que les physiciens ~~à un [illegible] plus réduit~~
s'efforceront sans doute de réaliser, ~~en prenant~~
[illegible] l'espérons les précautions nécessaires ~~indispensables~~

Figure 6 Handwritten text of Joliot's Nobel Prize address

ANNEX

Detailed list of manuscripts and equipment shown at the Royal Society Conversazione and their provenance.

Neutron pre-history

1. The OKLO phenomenon – display board produced by Dr Basil Rose, A.E.R.E. Harwell.
2. Rutherford's ideas on the neutron – reprints from Nerntz's theoretical chemistry, Rutherford's Bakerian Lecture to the Royal Society, Chadwick's Rutherford Memorial Lecture.
3. The problem of the nuclear electrons – correspondence between the Oxford University Press and Dr G Gamow about his book 'Structure of the Atomic Nucleus' (OUP Clarendon Press 1931). Excerpts from the Structure of the Atomic Nucleus by G. Gamow.
4. The Pauli neutron – copy of a letter from Pauli and copies of parts of two letters from Backett to Peierls (December 1930 and January 1931) – Peierl's Papers, Bodleian Library, Oxford.
5. The neturon nearly discovered – Professor Bothe's lecture notes for the Fall Term (1931-32) in manuscript and in translation. Copies of pages from the paper by Bothe and Becker – found by Professor O. Schmidt – Rohr (Max Planck Institut for Nuclear Physics, Heidelberg) in State Archives, papers of Professor Bothe.
6. The Curie-Joliot Experiment – manuscript notes for the 23rd, 24th and 27th December 1931 in the hand of Irene Curie and Frederick Joliot describing the effect of the 'fast gamma rays' from Ra/Be sources on hydrogenous materials. From Dr Helene Langevin, Institut du Radium, Paris. Photograph of Perran, Blackett and Frederick Joliot, Paris 1933 – source Helene Langevin.
7. Professor Bothe's comments after Chadwick's discovery 1932 – handwritten notes from the Bothe papers of lectures given in the summer term 1932.
8. Chadwick's sown description of the neutron discovery. Original at he Cyclotron Unit of the Hammersmith Hospital, London – given by Lady Chadwick to Dr Mary Catterall.
9. Photographs of Chadwick and of Chadwick with his laboratory assistant – Cavendish Laboratory Photographic Archives.
10. Professor Bothe's electrometer – from the Exhibition Hall at the Max Planck Institute for Nuclear Physics, Heidelberg.
11. Professor Bothe's gamma ray spectrometer using coincidence proportional counters (1954 approx.) from Exhibition Hall at the Max Planck Institute for Nuclear Physics, Heidelberg.
12. Chadwick's vacuum tube counter which he used in the neutron discovery from Exhibition Case, Cavendish Laboratory, Cambridge.
13. Chadwick's microscope built for observing scintillations (collection a the Cavendish Laboratory, Cambridge).