# Did the Cockcroft–Walton experiment really confirm Einstein's $\Delta E = \Delta mc^2$ first of all?

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**Abstract:** The original aim of Cockcroft and Walton's experiment was to disintegrate $Li^7$ with fast protons yielding alpha particles. Energy of 17.2 MeV was emitted. This experiment is regarded as the first confirmation of $\Delta E = \Delta mc^2$. The theoretical re-analysis of data as given by Cockcroft in his Nobel Lecture justifies only splitting of $Li^7$ by fast protons and is not consistent with $\Delta E = \Delta mc^2$. The values of the masses of proton, $Li^7$, and alpha particle have varied significantly due to improvements in the precision of instruments. If the values of reactants ($^1H = 1.0072$ u, $^7Li = 7.010\,4$ u) and products ($2 \times {}^4He = 8.002\,2$ u) are taken in account as existed at the time of Cockcroft's experiments, then percentage difference from $\Delta E = \Delta mc^2$ is 16.594. Soon after this, Bainbridge improved the value of the mass of $Li^7$ at 7.0130 amu. Then the percentage deviation from $\Delta E = \Delta mc^2$ decreased to 2.491. If the current values of the masses of reactants ($^1H = 1.0072764$ u, $^7Li = 7.01600455$ u) and products ($2\times {}^4He = 8.0030122$ u) are taken, then the percentage difference turns out to be 9.768. In a nutshell, it is concluded that such a significant experiment which is regarded as first confirmation of $\Delta E = \Delta mc^2$, be repeated with very precise instruments, eliminating all possible sources of errors, then results be compared with $\Delta E = \Delta mc^2$. Cockcroft and Walton's experiment has not been repeated by scientists, which increases the significance of the repetition. It is a basic principle of science that no conclusions can be drawn on the basis of a single observation. Results are widely accepted if repeatable. © *2014 Physics Essays Publication*. [http://dx.doi.org/10.4006/0836-1398-27.1.139]

**Résumé:** L'objectif initial de l'expérience de Cockcroft et Walton était de désintégrer $^7Li$ avec des protons rapides afin d'obtenir des particules alpha. Une énergie de 17,2 MeV a été émise. Cette expérience est considérée comme la première confirmation de la relation $\Delta E = \Delta mc^2$. Les nouvelles analyses théoriques des données fournies par Cockcroft dans son discours de réception du prix Nobel justifient seulement la scission des atomes de $^7Li$ par des protons rapides et ne sont pas compatibles avec la relation $\Delta E = \Delta mc^2$. Les valeurs des masses du proton, de $^7Li$ et des particules alpha ont varié de façon significative en raison d'améliorations de la précision des instruments. Si les valeurs des réactifs ($^1H = 1{,}0072$ u, $^7Li = 7{,}0104$ u) et des produits ($2\times {}^4He = 8.0022$ u) connues à l'époque de l'expérience de Cockroft sont prises en compte, alors la différence $\Delta E = \Delta mc^2$ en pourcentage est de 16,594. Peu après cela, Bainbridge a obtenu une meilleure valeur de la masse de $^7Li$ de 7,0130 amu. L'écart en pourcentage par rapport à $\Delta E = \Delta mc^2$ a alors diminué pour atteindre 2,491. Si les valeurs actuelles des masses des réactifs ($^1H = 1{,}0072764$ u, $^7Li = 7{,}01600455$ u) et des produits ($2\times {}^4He = 8{,}0030122$ u) sont utilisées, la différence en pourcentage devient alors 9,768. En bref, nous arrivons à la conclusion qu'une expérience si importante considérée comme la première confirmation de $\Delta E = \Delta mc^2$ devrait être reproduite avec des instruments très précis afin d'éliminer toutes les sources d'erreur possibles, et que les résultats devraient ensuite être comparés à $\Delta E = \Delta mc^2$. L'expérience de Cockcroft et Walton n'a pas été reproduite par des chercheurs, ce qui augmente l'importance de la reproduction de cette expérience. L'un des principes de base de la science est qu'aucune conclusion ne peut être tirée d'une seule observation. Les résultats deviennent largement acceptés s'ils sont reproductibles.

Keywords: Cockcroft–Walton Experiment

## I. COCKCROFT AND WALTON EXPERIMENT DOES NOT CONFIRM $\Delta E = \Delta MC^2$

The original aim of the Cockcroft and Walton experiment was disintegration of $Li^7$,[1–5]

$$p + Li^7 \rightarrow +\alpha + 17.2\,\text{MeV}.$$

According to precise measurements of Cockcroft, the energy released in the reaction was 17.2 eV or mass diminution of 0.01846 u (1 amu = 931.49 MeV based upon $\Delta E = \Delta mc^2$). Cockcroft in his Nobel lecture on December 11, 1951 highlighted the experiment for disintegration of $Li^7$ (7.0104 u) with fast protons. In the reaction, two alpha particles were

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produced. Sometime later, higher value of $Li^7$ was observed by Bainbridge at 7.0130u. Currently, the value of the mass of $Li^7$ is maximum (7.01600455 u). When mass is exchanged (annihilated or created) in a reaction, then energy also varies. Currently, energy emitted on annihilation of mass or energy materialized to mass is explained by Einstein's mass energy interconversion equation, $\Delta E = \Delta mc^2$.[6,7] Similar equations existed before[8–14] discovery of $\Delta E = \Delta mc^2$ and the same was critically analyzed after[15–30] the discovery of $\Delta E = \Delta mc^2$. So the same equation is applied to explain the observations of the Cockcroft and Walton experiment. Likewise, the values of other reactants and products have varied as precision in measuring equipments has increased. Consequently, the percentage deviation from the experiment and Einstein's $\Delta E = \Delta mc^2$ has varied. However, this experiment is regarded as the first confirmation of $\Delta E = \Delta mc^2$, thus this experiment must be repeated, taking into account the current precise values of reactants and products. Consequently, final conclusions can be drawn about the validity of $\Delta E = \Delta mc^2$ in the experiment, which has not been repeated since the Cockcroft and Walton experiment.

## II. COCKCROFT AND WALTON'S EXPERIMENTS IN 1932 AND $\Delta E = \Delta MC^2$

Initially, Cockcroft and Walton designed an experimental set up to accelerate protons which then split $Li^7$ with fast protons, whereby two alpha particles were obtained and energy was emitted. Obviously, the difference in the masses of reactants (protons and $Li^7$) and products (two alpha particles) was converted to energy. The energy emitted was explained with equation, $\Delta E = \Delta mc^2$. In the Cockcroft and Walton experiment, the energy measured with precise instruments is 17.2 MeV (equivalent to 0.01846 u).

First, let us analyze the energy considerations in view of the atomic masses of reactants and products existing at time of Cockcroft's experiment.[4,5]

$$\begin{aligned} &{}^7\mathrm{Li} = 7.0104\,\mathrm{u}\,(\mathrm{Costa}) \\ &{}^1\mathrm{H} = 1.0072\,\mathrm{u} \\ &\text{Mass of reactants} = 8.0176\,\mathrm{u}, \end{aligned} \tag{1}$$

$$2 \times {}^4\mathrm{He} = 8.0022\,\mathrm{u}, \tag{2}$$

$$\text{Mass decrease} = 8.0176\,\mathrm{u} - 8.0022\,\mathrm{u} = 0.0154\,\mathrm{u}. \tag{3}$$

According to Einstein's $\Delta E = \Delta mc^2$, the mass is converted to energy ($1\mathrm{u} = 931.49$ MeV). So the energy equivalent to 0.0154 u is given by 14.3449 MeV.

$$\begin{aligned} \text{Energy emitted in the reaction } &= 0.0154 \times 931.49 \\ &= 14.3449\,\mathrm{MeV}. \end{aligned} \tag{4}$$

Furthermore, Cockcroft and Walton had measured the energy emitted precisely at 17.2 MeV. Thus,

$$\text{Energy emitted in the experiment} = 17.2\,\mathrm{MeV}. \tag{5}$$

A further difference in the theoretical (based on $\Delta E = \Delta mc^2$) and experimental values of energy is 2.8551 MeV (17.2 − 14.3449 MeV). Now from theoretical and experimental values of energy, we have

$$\text{Percentage difference} = 16.594. \tag{6}$$

This is a considerable deviation. Thus, Einstein's mass energy interconversion equation $\Delta E = \Delta mc^2$ is not confirmed, contrary to the belief that this experiment provides the first confirmation to $\Delta E = \Delta mc^2$.

## III. BAINBRIDGE IMPROVED THE MEASUREMENT OF MASS OF $LI^7$

After a few years, the more and more precise measurements of the mass of $Li^7$ continued. Cockcroft and Walton took the value of the mass of $Li^7$ equal to 7.010 4 u. However, Bainbridge improved the precision of the measurement of the mass of $Li^7$ to 7.0130 u. Now the difference between the mass used by Cockcroft and Bainbridge is 0.0026 u (7.0130 u − 7.010 4 u) or 2.421874 MeV. Thus, the energy emitted can be experimentally calculated:

For reactants,

$$\begin{aligned} &{}^1\mathrm{H} = 1.0072\,\mathrm{u} \\ &\mathrm{Li}^7 = 7.0130\,\mathrm{u} \\ &{}^1\mathrm{H} + \mathrm{Li}^7 = 8.0202\,\mathrm{u}. \end{aligned} \tag{7}$$

For products,

$${}^4\mathrm{He} + {}^4\mathrm{He} = 8.0022\,\mathrm{u}. \tag{8}$$

$$\begin{aligned} &\text{Difference between masses of reactants and products} \\ &\quad = 0.0180\,\mathrm{u}. \end{aligned} \tag{9}$$

$$\begin{aligned} &\text{Energy emitted in reaction } (1\mathrm{u} = 931.49\,\mathrm{MeV}) \\ &\quad = 16.76682\,\mathrm{MeV}. \end{aligned} \tag{10}$$

Now the difference in theoretically predicted and experimentally observed values of the mass is (17.2 − 16.76682 MeV) = 0.43318MeV. Thus,

$$\text{Percentagedifference} = 2.491. \tag{11}$$

This is a significant deviation from $\Delta E = \Delta mc^2$, even if the mass of $Li^7$ is taken at 1.0130 u. Now, this is what Cockcroft and Walton stated. Thus. when the precisely measured mass as obtained by Bainbridge is used then the mass difference (between reactants and products) increases to 0.0180 u.[4,5] Cockcroft mentioned that this value is close to the predicted value 0.01846 u. However, the difference between these two values is 2.555%. Thus, Cockcroft's deduction is not justified.

## IV. THE LATEST ACCEPTED MASSES OF THE PROTON, LITHIUM 7 AND ALPHA PARTICLES

The increase in precision in measurements of atomic masses is a continuous process and will continue into the future. Earlier the masses of various reactants and products at time of Cockcroft and Bainbridge were of course used. Now, the latest accepted masses of reactants and products

TABLE I. Variations in values of energy ($\Delta E = \Delta mc^2$) in disintegration of lithium by fast protons in the Cockcroft and Walton experiment of 1932.

| Sr.No. | Scientist | Mass (u) | Mass difference (u) | Energy theoretical (MeV) | Energy observed (MeV) | Percentage difference |
|---|---|---|---|---|---|---|
| 1 | Cockcroft and Walton | Li = 7.0104<br>$^1$H = 1.0072<br>2 α = 8.0022 | 0.0154 | 14.3449 | 17.2 | 16.594 |
| 2 | Cockcroft and Walton(Bainbridge) | Li = 7.0130<br>$^1$H = 1.0072<br>2 α = 8.0022 | 0.018 | 16.76682 | 17.2 | 2.491 |
| 3 | Latest values of mass | Li = 7.01600455<br>$^1$H = 1.0072764<br>2 α = 8.0030122 | 0.0202687 | 18.88 | 17.2 | 9.768 |

are taken into account in the equation and energy ($\Delta E = \Delta mc^2$) is calculated. Even then the Cockcroft and Walton experiments does not confirm $\Delta E = \Delta mc^2$. This is contrary to the fact that the scientific community believes that the Cockcroft experiment provides the first confirmation to $\Delta E = \Delta mc^2$. The more precise masses of protons, lithium, and alpha particles must be used in reactants and products to draw confirmatory conclusions. The energies are calculated as in previous cases.

$$^1H = 1.0072764\,u$$
$$^7Li = 7.01600455\,u \tag{12}$$
$$^1H + {}^7Li = 8.02328095\,u,$$

$$^4He + {}^4He = 2 \times 4.0015061 = 8.0030122\,u. \tag{13}$$

Difference in masses of reactants and products

$$= 8.02328095\,u - 8.0030122\,u = 0.0202687\,u. \tag{14}$$

Again, the conversion factor between mass and energy is derived from $\Delta E = \Delta mc^2$.

$$\text{Energy emitted in reaction} = 931.49 \times 0.0202687\,u = 18.88\text{MeV}. \tag{15}$$

The energy experimentally measured precisely in the Cockcroft and Walton experiment is 17.2 MeV. The same energy is used while interpreting the reaction using the mass of $Li^7$ obtained by Bainbridge and original the Cockcroft experiment. The difference between theoretical and experimental values is 1.68 MeV (18.88 – 17.2 MeV). Thus,

$$\text{Percentage difference} = 9.768\,\text{MeV}. \tag{16}$$

Hence this experimental data does not justify the claim that $\Delta E = \Delta mc^2$ is confirmed by the Cockcroft–Walton experiments. The measurement of masses of reactants and products used were those existing at time of Cockcroft and Walton. But now standards of measurements of masses and energy are far higher than existing in 1930s. The experimental values of various parameters (Cockcroft data, Bainbridge data and current data) are compared in Table I. The final conclusion is that the data given by Cockcroft are not consistent with $\Delta E = \Delta mc^2$, even when the most precise values of reactants are products are taken. So the experiment needs to be conducted again, eliminating all possible sources of errors, as this experiment illustrates a significant issue in mass–energy interconversion.

Even the repetition of the most established experiments leads to improved results. All the astronomical data are based upon the universal gravitational constant G, and even now experiments involving measurement of G are continuously conducted. Currently, the accepted value for the gravitational constant is $6.673\ 84 \times 10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$, but the recently measured[31] value is much higher, i.e., G = 6.67545 (18) $\times 10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$. The mass of earth ($M = gR^2/G$) with the latest value of G is 0.024% lower. It is a basic principle of science that no conclusions can be drawn on the basis of a single observation. Results are widely accepted if repeatable.

So repetition of various experiments is very common in science. Thus, some noble scientific results are expected when the Cockcroft and Walton experiments again conducted. There is no evidence that the Cockcroft and Walton experiment was ever repeated. Repetitions would be very significant experiments in the understanding of $\Delta E = \Delta mc^2$.


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