Simulating Fusion

Part of a Series of Activities in Plasma/Fusion Physics
to Accompany the chart
Fusion: Physics of a Fundamental Energy Source

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Preface

This activity is intended for use in high school and introductory college courses to supplement the topics on the Teaching Chart, ***Fusion: Physics of a Fundamental Energy Source,*** produced by the Contemporary Physics Education Project (CPEP). CPEP is a non-profit organization of teachers, educators, and physicists which develops materials related to the current understanding of the nature of matter and energy, incorporating the major findings of the past three decades. CPEP also sponsors many workshops for teachers. See the homepage **www.CPEPweb.org** for more information on CPEP, its projects and the teaching materials available.

The activity packet consists of this student activity and separate notes for the teacher. The Teacher's Notes include background information, equipment information, expected results, and answers to the questions that are asked in the student activity. The student activity is self-contained so that it can be copied and distributed to students. Teachers may reproduce parts of this document for their classroom use as long as they include the title and copyright statement. Page and figure numbers in the Teacher's Notes are labeled with a T prefix, while there are no prefixes in the student activity.

Developed in conjunction with the Princeton Plasma Physics Laboratory and funded through the Office of Fusion Energy Sciences, U.S. Department of Energy, this activity has been field tested at workshops with high school and college teachers.

We would like feedback on this activity. Please send any comments to:

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to Accompany the chart
Fusion: Physics of a Fundamental Energy Source

In this activity you will simulate nuclear fusion, the joining together of two nuclei to form a new nucleus, and investigate how fusion depends on a number of different variables. This simulation will use a physical model to generate data analogous to the events that occur in a real fusion reactor.

General background:

For particular nuclei in a certain amount of time the number of fusions (symbolized as “N”) that one gets in a reactor depends on the rate at which fusion occurs, which in turn depends on the rate at which nuclei “collide” or come close enough for fusion to take place. It also depends on there being enough kinetic energy to result in the nuclei coming close enough together in spite of the repulsive electrical forces between positive nuclei. At the high temperatures necessary to achieve the required kinetic energy, a plasma forms. A plasma consists of freely moving charged particles, in this case the nuclei.

The total number of collisions depends in part upon the time during which the plasma is hot enough for collisions to take place. Represent time with the symbol “τ.”

The rate of collisions also depends upon how many nuclei there are in a given volume. This is the particle density. Represent particle density with the symbol “n.”

The rate of collisions should depend upon how fast the nuclei are moving. However, in a real experiment we can’t measure speeds of individual nuclei. Instead we need a variable that relates to the plasma as a whole that depends on speed and is measurable. This variable is temperature. Represent temperature with the symbol “T.”

Your primary goal in the following activity is to develop and use a hands-on model of colliding nuclei to determine experimentally how the number of fusions in a fusion reactor depend on interaction time, τ, and particle concentration, n, at a particular temperature. You will model particles with bottle tops (with Velcro attached) and will confine them in a box or bag. Since temperature is related to the speed of the particles, you will simulate temperature by how rapidly you shake your system of particles (bottle tops).

Materials:

A closable box or bag to simulate a fusion reactor and two sizes of bottle tops to simulate two different types of nuclei. The bottle tops should have Velcro on one side.

Procedures:

1. You won't be able to model temperature very quantitatively, but in order to keep the simulated temperature from being an unintentional variable, it will be important to control the simulated temperature by practicing shaking the system at a nearly constant rate, time after time, until you can do so reproducibly.

   Start with about 50 of each type of nucleus in your reactor and gently shake for 10 seconds. Open the reactor, and count how many of the nuclei have fused together. Count each combination as one fusion.

   After separating the nuclei that fused and replacing them in the box or bag, repeat this a few times to get a sense of how repeatable the results are. Once the counts from repeated shakings have become fairly consistent, the last few numbers of fusions should be averaged as the number, N, of simulated fusions during 10 s.

2. Vary the shaking time, τ, while holding shaking vigor and particle density constant. You might use times in addition to the 10s that you've already done, like 20s, 30s, 40s, 50s and 60s. Do each of these at least three times to get a good average.

3. Graph the number of fusions, N, versus τ.

4. To vary particle concentration, n, increase or decrease the number of one of the types of nuclei. For example, if you used 50 of each type initially, keep one at 50, and vary the other to 25, then to 75 and then to 100. Keep the time the same, use 10 s for each trial, shaking in the way that you found easiest to reproduce in the previous trials (you will use your data for 10 s and n = 50 from the first part as one of your data points for this part). Do this at least three times for each concentration and find an average.

5. Graph the number of fusions, N, versus n.

6. You should now have two graphs that relate the number of fusions to other variables. In the graph shown in "Achieving Fusion Conditions" on the bottom right of the *Fusion: Physics of a Fundamental Energy Source* chart, note that the product of n and τ is plotted against T. Since you have not varied T, look at one value of T that is under the oval for "sustained fusion." Fusion reactors will be successful if the number of fusions, N, is large enough.

   Are your relationships between N and n and between N and τ consistent with the graph of $n\tau$ versus T? (That is, does the chart graph indicate that the number of fusions would depend on n and τ the way your experiment did?)

   In the graph of $n\tau$ versus T, for a range of temperatures from less than 10^8 K to about 4 x 10^8 K, the product $n\tau$ needed to achieve successful reactor operation drops (the bottom of the oval gets lower).

   What does this suggest about the effect of increasing temperature in this range on the achievement of successful reactor operation?

   Beyond a certain temperature, about 4 x 10^8 K, the product $n\tau$ needed to achieve successful reactor operation increases (the bottom of the oval gets higher).

   What does this suggest about the effect of increasing temperature in this range on the achievement of successful reactor operation?

   Look at the chart graph "Fusion Rate Coefficients" (lower left of the chart).

   Does the plot of Rate Coefficient (indicates the probability of the reaction) versus Temperature for the D + T (deuteron + triton) reaction explain this effect?

   Your final result can be found by combining the two proportionalities. Ask your teacher for help with this.

Questions:

1. In what ways did your system model a real fusion reactor well?

2. In what ways did your system model a real fusion reactor poorly?

Optional Activity:

You've probably figured out that the fusion rate should depend on the temperature, and that this is so is shown in the chart graph "Fusion Rate Coefficients." In the activity you've done you weren't asked to use your bottle top model to find out how fusion reaction rate depends on temperature. That is the subject of this additional activity.

Procedures:

1. (Note that this is the same as #1 in the original activity. You can just use the results you already have if you don't want to repeat this.) Start with about 50 of each type of nucleus in your reactor and gently shake for 10 seconds. Open the reactor, and count how many of the nuclei have fused together. Count each combination as one fusion.

   After separating the nuclei that fused and replacing them in the box or bag, repeat this a few times to get a sense of how repeatable the results are. Keep doing this until you are satisfied with the repeatability of the results.

2. Again separate the nuclei replace them, and repeat the above with a slightly more vigorous, but constant, shaking to represent twice the temperature from the first set of trials. If you really want to get close to doubling T, try to get a sense for what will increase the speed by about 40%. Again record results from each trial and calculate an average.

3. Repeat the above one or two more times with still more vigorous shaking. For those who really think that they can do this, try for 70% faster particles for 3 times the original T and twice the speed for 4 times the original T. Record the results.

4. Construct a graph of the average number of fusions, N, versus T.

5. From your three graphs (two from the previous activity) of the number of fusions versus the variables τ, n and T determine three proportionalities and use these with the guidance of your teacher to determine how the number of fusions depends on τ, n and T in combination.