# Additional exercises v.1.0

This document contains additional exercises to accompany Module 1: Fusion basics of the FuseNet educational materials for secondary schools.

**Legend:**

*: introductory exercise: short exercise, requires little to no calculation.

**: intermediate exercise, could require some calculation or some more advanced thinking.

***: challenging  exercise, might require advanced calculation or derivation.

## Chapter 1: The discovery of fusion

**Exercise A.1: Proton-proton chain

In this module, you have been introduced to the p-p chain. The p-p chain is a series of reaction, that the uses to generate its energy. It is not a chain reaction, as one reaction does not initiate the next reaction. Every reaction can happen independently if the correct particles are present. Also, while it is called a single chain, the p-p chain consists out of different branches. The simplest branch is called PP I and consists out of four reactions.

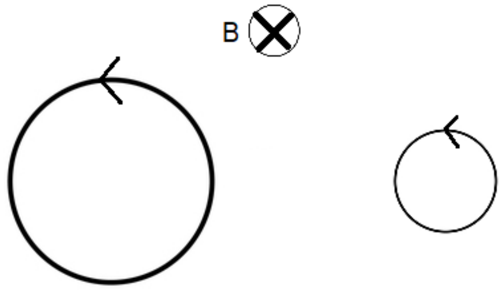
$$
\begin{aligned}
&(1)\ p + p \rightarrow {}^{2}_{1}D^{+} + \nu_e + e^{+} \\
&(2)\ e^{+} + e^{-} \rightarrow 2\,\gamma \\
&(3)\ {}^{2}_{1}D^{+} + p \rightarrow {}^{3}_{2}He^{2+} + \gamma \\
&(4)\ {}^{3}_{2}He^{2+} + {}^{3}_{2}He^{2+} \rightarrow {}^{4}_{2}He^{2+} + 2\,p
\end{aligned}
$$

a. How many times should each reaction occur so that the net result is $4\,p + 2\,e^{-} \rightarrow {}^{4}_{2}He^{2+} + + \boldsymbol{A}\,\gamma + \boldsymbol{B}\,\nu_e$?
b. What are the values for A and B?

**Exercise A.2: Accelerator fusion

The first fusion on earth was performed by shooting hydrogen isotopes onto each other with particle accelerators. This method is no longer used in fusion research because scattering makes this method very inefficient. Can you explain why scattering decreases the efficiency of this method.

## Chapter 2: First devices




*Exercise A.3: Gradient drift

Two hydrogen ions with the same speed move around in a magnetic field. The ions move only perpendicular to the magnetic field. The magnetic field points in the paper. Its strength is not homogenous but changes linearly from left to right. In the picture above, the orbits of the hydrogen ions have been drawn, as if the magnetic field was homogenous at their location.

a) Is the magnetic field stronger near the left particle, or the right particle? Can you explain why?
b) Based on the previous answer, does the magnetic field increase or decrease when moving from left to right?
c) How do you expect the orbit of a particle to look like in such a magnetic field? Make a drawing of its trajectory. Is it still a closed orbit? If not, in which direction do the ions drift?

*Exercise A.4: Important names

In chapter 2 a multitude of important names where mentioned. Let's see if you still remember them! Fill in the following table:

| | | | |
|---|---|---|---|
| Design names | | | |
| country | | | |
| inventors | | | |
| Names | | | |

Write down in the first row, the names of the three designs explained in chapter 2. In the second row, write down the country in which the design was invented. In the next row, write down the names of the inventors that are mentioned for the different designs. In the last row, write down all the names of devices mentioned in chapter 2 for each design.

*Exercise A.5: Stellarator vs Tokamak

In chapter 2, you were introduced to three different designs for fusion devices. Of these, the stellarator and tokamak show some similarities. However, there is a very important difference between these designs.

a. What is the most important difference between the two designs?
b. What is an important consequence of this difference?

## Chapter 3: Breakthrough and breakdown

*/**Exercise A.6: Q-factor*

For many years, fusion researchers have attempted to show that the Q-factor could be increased above 1.

a. What is the Q-factor and why is it so important to reach Q>1?
b. If we were to achieve Q>1 right here and now, could we start making fusion powerplants that produce sustainable electricity?

## Chapter 4: ITER

* Exercise A.7: Fusion research in your own country – internet assignment.

Every country has its own policy and investment in fusion. Some countries only fund one or two projects, while others have large research campaigns consisting of many experiments. Some countries do nothing with fusion, while others have already made detailed plans on when to start working on the big DEMO reactors. In this exercise, you are encouraged to look up what your country is doing with fusion. Try to answer the following questions;

a. How much money is your country spending on fusion research?
b. Do they have their own experiments or do they only cooperate in big projects or not at all?
c. Is your country planning on making a DEMO reactor?
d. Are you happy with how much your country is doing for fusion research? If not, do you want your country to invest more or less in fusion?

*/*** Exercise A.8: Fusion and you

Now that you know a bit more about the history of fusion, how do you look at it? Are you happy to see that so many countries make serious effort to make fusion work or are you sceptical that it will work? What would you think if your energy supplier started supplying energy generated by a fusion reactor? What do you think that fusion energy biggest strength and biggest weakness are?