Name: _____ **Date:** _____

MARVLS: The Tokamak

Learning Objective	I can breakdown a nuclear fusion reaction into smaller components, to better understand how nuclear fusion creates energy.

Introduction: The Tokamak

Watch the video (www.tinyurl.com/wrdtokamak) to answer the following questions:

What is the main goal of creating of the Tokamak?

Materials

- Pencil
- Smartphone
- Merge Cube (Download and print for students)
- MARVLS: Plasma App
  to install: Scan QR Code below
  And follow prompts to install.

App Store
MARVLS: Plasma Physics

Google Play Store
MARVLS: Plasma Physics

Time to View in 3D AR! (...that's three dimensional augmented reality!!)

MARVLS Navigation

1. **Click** the view in AR button on the bottom right of the screen.

2. **Point** your phone's camera toward the Merge Cube.
   Change the cube's orientation until the three dimensional model appears.

What am I looking at?

The buttons on the bottom of the screen will show and hide the important components of the Tokamak. Play with the buttons and review the associated vocabulary word below.

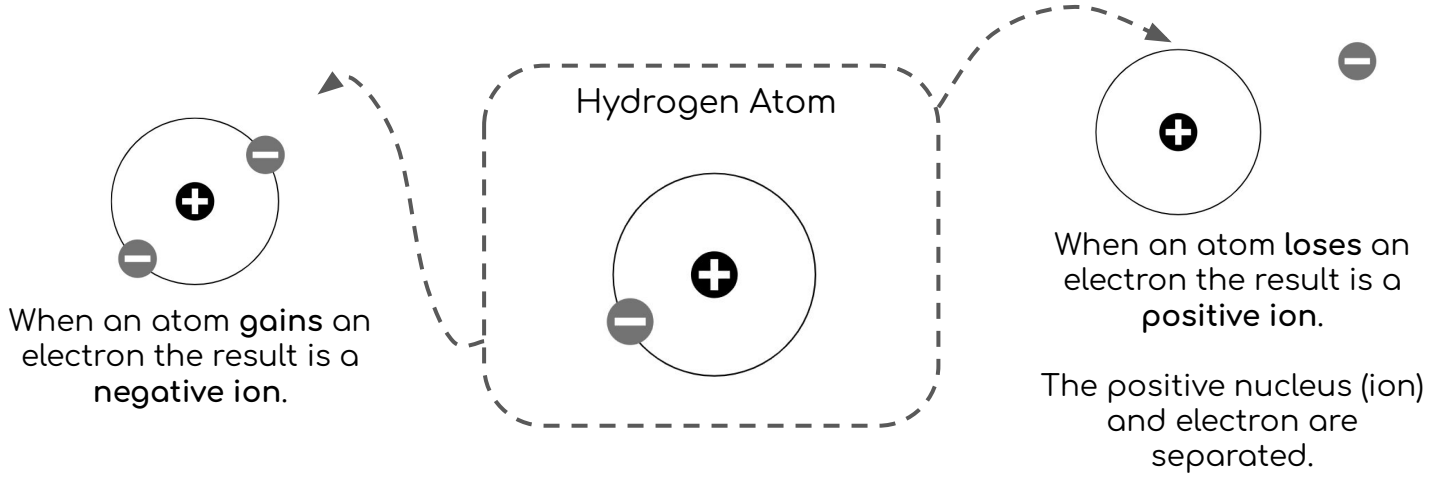
1. Plasma: an ionized gas containing particles (positive ions and free electrons)
2. Current: movement of particles
3. B field: a vector that describes the magnetic influence on moving electric charges
4. Toroidal: electromagnet that creates an circling magnetic field inside of the donut
5. Poloidal: electromagnet that creates a vertical magnetic field
6. Solenoid: electromagnet that creates a magnetic field at the center of the cylinder

Reactions in the tokamak occur when two nuclei of hydrogen isotopes combine.

The nuclei are separated from the electrons when the isotopes are heated up and ionized.
Now, we have the positive ions which will combine in the nuclear fusion reaction and produce energy.

Pause: Let's break down the hydrogen isotope.

Ionization of Hydrogen



Hydrogen Isotopes

MARVLS Navigation

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Observe: Click through the different buttons in the "**Hydrogen Isotope**" section.

- ☐ H+
- ☐ D+
- ☐ T+

What stays the same in all three isotopes?
What is different?

Define: An <u>isotope</u> is an atom of the same element that has _____

number of **protons** and _____ number of **neutrons**.

Reactions in the tokamak occur when two nuclei of hydrogen isotopes combine.

Pause: How can positive ions combine?

The nuclei are separated from the electrons when the isotopes are heated up and ionized.
Now, we have the positive ions which will combine in the nuclear fusion reaction and produce energy.

Electrostatic Forces

Use the rules of electrostatic forces to identify which combination of particles attract and which particles repel.

Attract

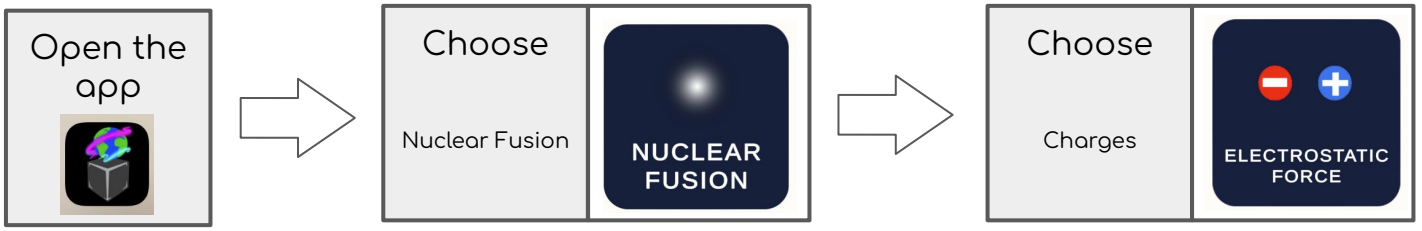
- ☐ Positive/Positive
- ☐ Negative/Negative
- ☐ Positive/Negative

Repel

- ☐ Positive/Positive
- ☐ Negative/Negative
- ☐ Positive/Negative

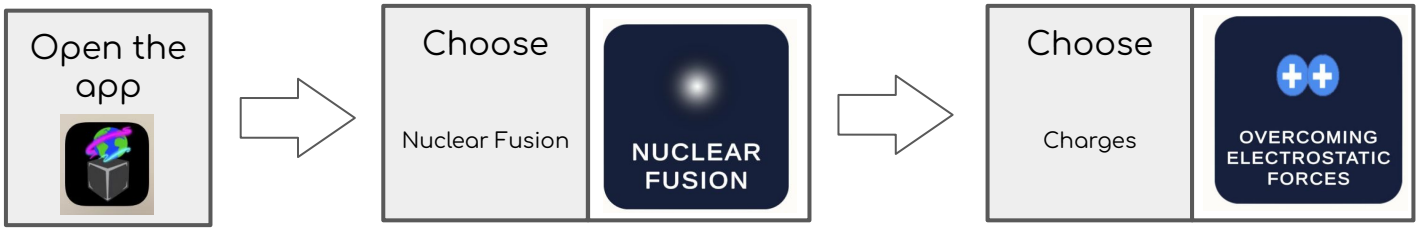
* Need help? Check out the electrostatic force model using the navigation below.

MARVLS Navigation



Overcoming Electrostatic Force

MARVLS Navigation



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Observe: Move the slider at the bottom of the screen to change the conditions of the plasma.

- ☐ snowflake
- ☐ little fire
- ☐ big fire

What did you observe as you tested the different conditions? In terms of heat or temperature, what conditions allow for the positive ions to react?

Reactions in the tokamak occur when two nuclei of hydrogen isotopes combine.

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Pause: Let's breakdown the nuclear fusion reaction.

Modeling the Nuclear Fusion Reaction

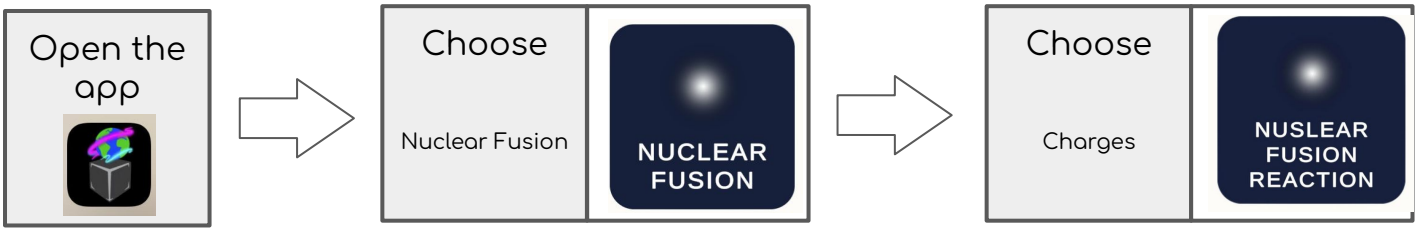
The nuclear fusion reaction starts with a *deuterium nucleus* and a *tritium nucleus*, which are seen on the left side of the reaction below. When these particles react, a *helium nucleus* and *neutron* are formed. We see these products on the right side of the arrow.

Starting materials				Products		
D^+	+	T^+	→	He^{2+}	+	neutron

KEY: D^+ = Deuterium nucleus T^+ = Tritium nucleus He^{2+} = Helium nucleus

Fusion Reactions in AR

MARVLS Navigation



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Observation 1: Press play to watch the nuclear fusion reaction occur. → Click on the boxes below and take a closer look at how the reaction begins and ends. ☐ Starting materials ☐ Products ☐ View reaction	What happens during the nuclear fusion reaction? Explain what is present at the beginning and end of the reaction.

Reactions in the tokamak occur when two nuclei of hydrogen isotopes combine.

The nuclei are separated from the electrons when the isotopes are heated up and ionized.
Now, we have the positive ions which will combine in the nuclear fusion reaction and produce energy.

Let's see how each piece of the tokamak supports the nuclear fusion reaction.

Let's go back to the Tokamak

1. **Click** the view in AR button on the bottom right of the screen.

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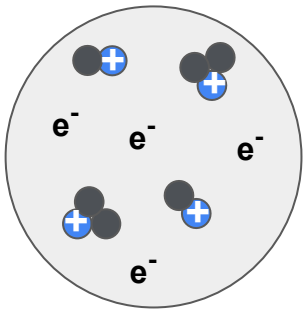
What we know:
Within the Tokamak there is a "soup" of charged particles which consist of ions and electrons which will be used as the starting point of the nuclear fusion reaction.
This soup of charged particles is found in the plasma.

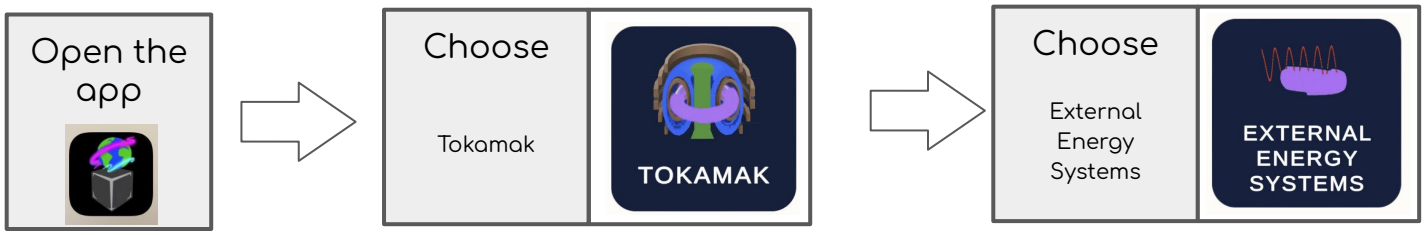


Plasma is very hot, however in order to create a nuclear fusion reaction we need to add additional energy or heat!

Observe: Click on the buttons so that Plasma is in "show" mode, hide other features to concentrate on the plasma. Then begin to show other features.

Predict: How do you think scientist add heat or energy to the plasma in the tokamak?

Use the navigations below to learn more about how we add energy or heat to the plasma to create a nuclear fusion reaction.



What we know:
Plasma is a very hot substance, so hot that we do not have a physical material we can use we must contain it without actually touching it.

The Tokamak uses electromagnetic fields coming from multiple directions to control and contain the plasma.

Review the video from the warm up of this lesson,
go to timestamp: 6:58-8:56

www.tinyurl.com/wrdtokamak

Observe: View the different electromagnets by clicking the following:

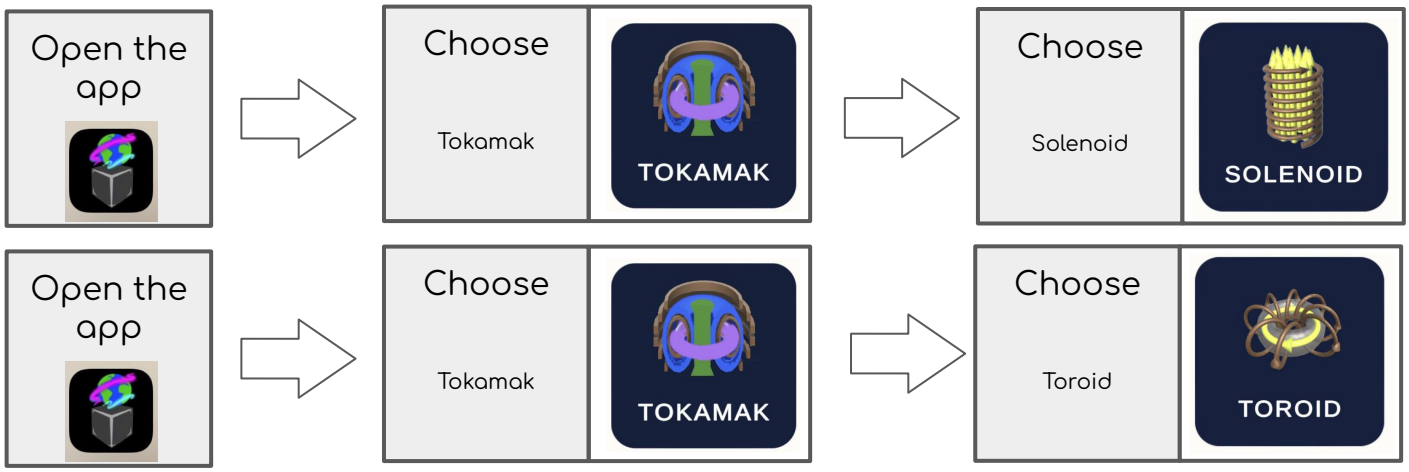
- ☐ Toroidal
- ☐ Poloidal
- ☐ Solenoid

Observe: View the field and current created by the electromagnets

- ☐ Current
- ☐ B Fields

Experiment: How would removing one or more of the electromagnets impacts the overall current or B field?

Use the navigations below to learn more about two of the electromagnets used in the Tokamak in isolation. Using these models you will see the magnetic fields created when a current flows in the coils.



Final Thoughts

1. What charges do the two particles have that need to come together in a fusion reaction? Are these charges the same as each other or different?

2. What is the purpose of heating up the plasma? What forces need to be overcome?

3. In simple terms, what is the product of nuclear fusion?

4. What is the purpose of the different magnetic fields in the Tokamak?

Think → Write → Pair → Share

Why do you think scientist are investing so much time and energy into nuclear fusion and instruments like the Tokmak?