Extended Scenarios

Scenario 1

Use the following information to answer the next five questions.

Transuranic Elements

Transuranic elements have more protons than uranium. Because all transuranic elements have a relatively short half-life, they are almost absent from our solar system. Physicists have made transuranic elements by bombarding heavy ions with magnesium ions and oxygen ions.

In a particular bombardment, a physicist uses magnesium ions ($^{28}\text{Mg}^{2+}$) with a mass of 4.67×10^{-26} kg and accelerates them to a kinetic energy of 1.64×10^{-13} J.

1. In this bombardment, the speed of a magnesium ion is
   - **A.** 1.87×10^{6} m/s
   - **B.** 2.65×10^{6} m/s
   - **C.** 3.51×10^{12} m/s
   - **D.** 7.02×10^{12} m/s

2. The electric potential difference that accelerates the magnesium ion is
   - **A.** 9.76×10^{-7} V
   - **B.** 1.95×10^{-6} V
   - **C.** 5.13×10^{5} V
   - **D.** 1.03×10^{6} V

3. Magnesium-28 undergoes a beta negative decay according to the nuclear reaction equation

A. $^{28}_{12}\text{Mg} \rightarrow {}^{28}_{13}\text{Mg} + {}^{0}_{-1}\text{e} + \bar{\nu}$

B. $^{28}_{12}\text{Mg} \rightarrow {}^{28}_{13}\text{Al} + {}^{0}_{-1}\text{e} + \bar{\nu}$

C. $^{28}_{12}\text{Mg} \rightarrow {}^{28}_{11}\text{Na} + {}^{0}_{-1}\text{e} + \bar{\nu}$

D. $^{28}_{12}\text{Mg} + {}^{0}_{-1}\text{e} + \bar{\nu} \rightarrow {}^{28}_{11}\text{Na}$

4. A physicist starts a 7.0 day experiment with 0.20 g of magnesium-28. If the half-life of magnesium-28 is 21 h, then the mass of magnesium-28 remaining at the end of the experiment will be

A. 1.8×10^{-1} g
B. 3.9×10^{-3} g
C. 7.8×10^{-4} g
D. 9.5×10^{-8} g

5. In order to produce dubnium-262 ($^{262}_{105}\text{Db}$), berkelium-249 ($^{249}_{97}\text{Bk}$) is bombarded with very fast-moving oxygen nuclei. This reaction produces five neutrons. The nuclear reaction equation for this production of dubnium-262 is

A. $^{13}_{8}\text{O} + {}^{249}_{97}\text{Bk} \rightarrow {}^{262}_{105}\text{Db} + 5\,{}^{1}_{0}\text{n}$

B. $^{14}_{8}\text{O} + {}^{249}_{97}\text{Bk} \rightarrow {}^{262}_{105}\text{Db} + 5\,{}^{1}_{0}\text{n}$

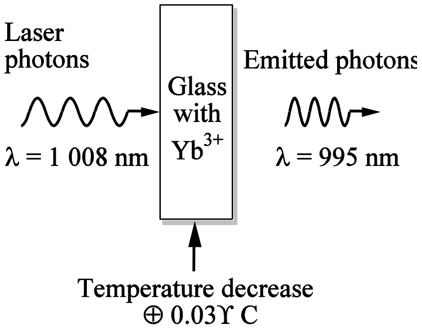
C. $^{14}_{8}\text{O} + {}^{249}_{97}\text{Bk} \rightarrow {}^{262}_{105}\text{Db} + {}^{1}_{0}\text{n}$

D. $^{18}_{8}\text{O} + {}^{249}_{97}\text{Bk} \rightarrow {}^{262}_{105}\text{Db} + 5\,{}^{1}_{0}\text{n}$

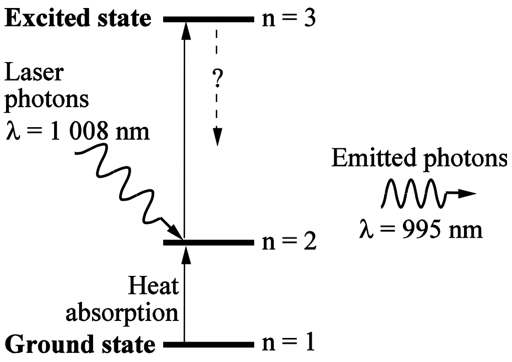
Scenario 2

Use the following information to answer the next four questions.

Physicists have produced “optical cooling” by shining a laser onto glass that contains ytterbium ions (Yb^{3+}). The glass with ytterbium ions absorbs the laser photons and radiates photons with a shorter wavelength, as shown below. This process decreases the temperature of the glass with ytterbium ions.



One theory suggests that the cooling occurs because of electron movement between energy levels in the ytterbium ions, as shown below. If a ground state electron in an ytterbium ion absorbs a small amount of thermal energy, it moves to the second energy level (n = 2). The ion then absorbs the laser photon, which moves the electron to the excited state (n = 3). The cooling occurs when the ytterbium ion emits a photon.



1. When the glass cools, the ions lose both the thermal energy and the energy that was absorbed from the laser photons. The electron energy level transition that occurs is from energy level

   A. n = 3 to n = 2
   B. n = 3 to n = 1
   C. n = 2 to n = 1
   D. n = 2 to n = 3

Numerical Response

2. The frequency of the laser photons, expressed in scientific notation, is $\boldsymbol{a.b} \times 10^{\boldsymbol{cd}}$ Hz. The values of ***a, b, c***, and ***d*** are _____ , _____ , _____ , and _____ .

(Record your **four-digit answer** in the numerical-response section on the answer sheet.)

3. The energy difference between a laser photon and an emitted photon is

   A. 1.97×10^{-19} J
   B. 2.00×10^{-19} J
   C. 2.58×10^{-21} J
   D. 8.62×10^{-33} J

4. Visible light has frequencies that range between 4.3×10^{14} Hz (red) and 7.5×10^{14} Hz (violet). Which of the following statements **best** describes the absorbed laser photon and the emitted photon in the optical cooling experiment?

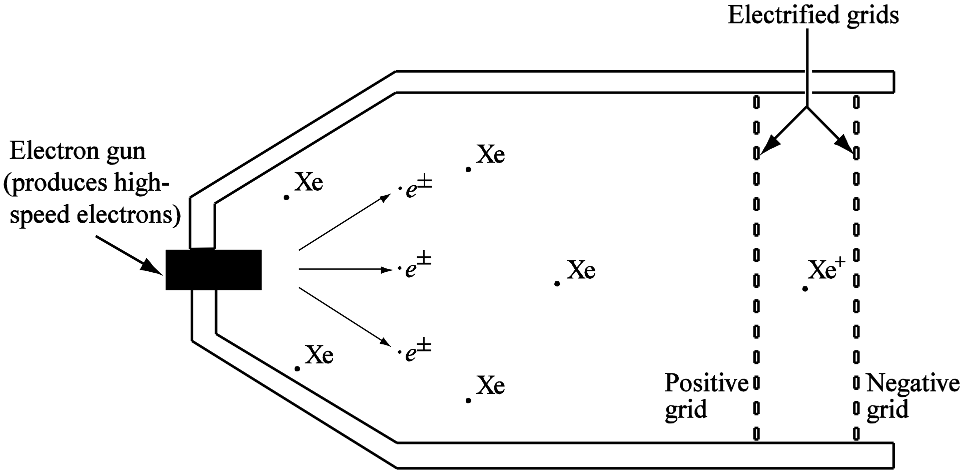
   A. Both photons are in the infrared range.
   B. Both photons are in the ultraviolet range.
   C. Both photons are in the visible light range.
   D. One photon is in the visible light range, and one is not in the visible light range.

Scenario 3

Use the following information to answer the next seven questions.

The Deep Space 1 mission (DS1) uses a ion propulsion system (IPS) on the DS1 capsule. The IPS involves ionizing atoms of xenon, accelerating them through an electric field produced by electrified grids, and ejecting the ions into space behind the capsule.

IPS Chamber of the DS1 Capsule



In the IPS chamber, high-speed electrons collide with xenon atoms. These collisions can ionize xenon atoms. The electric field then accelerates the ions and ejects them from the IPS chamber, which propels the DS1 capsule forward.

IPS Operating Specifications for DS1

propellant ions	Xe^+
total mass of propellant	81.5 kg
mass of DS1 capsule (without propellant)	489.5 kg
energy required to ionize a xenon atom	12.1 eV
mass of a single xenon atom	2.18×10^{-25} kg
exit speed of xenon ions	43.0 km/s

1. The minimum electron speed necessary to ionize xenon atoms is

   A. 2.66×10^{31} m/s
   B. 5.15×10^{15} m/s
   C. 4.25×10^{12} m/s
   D. 2.06×10^{6} m/s

2. The electric potential difference across the electrified grids that is required to accelerate a xenon ion from rest to its exit speed is

   A. 2.93×10^{-5} V
   B. 1.26×10^{-3} V
   C. 1.26×10^{3} V
   D. 4.71×10^{29} V

3. If all of the xenon propellant could be expelled in a single short burst, the change in the speed of the DS1 capsule after all the fuel has been exhausted would be

   A. 6.14 m/s
   B. 7.16 m/s
   C. 6.14×10^{3} m/s
   D. 7.16×10^{3} m/s

4. The physics principle that **best** describes the propulsion of the DS1 capsule is the law of conservation of

   A. charge
   B. energy
   C. momentum
   D. nucleon number

Numerical Response

5. As xenon ions in the exhaust stream behind the DS1 capsule interact with other charged particles in space, the xenon ions become neutral atoms, and in the process, emit photons. The maximum frequency of these photons, expressed in scientific notation, is $b \times 10^{w}$ Hz. The value of b is __________.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Use the following additional information to answer the next two questions.

One isotope of xenon, xenon-133, is an unstable isotope that undergoes beta-negative decay and has a half-life of 5.24 days.

Numerical Response

6. If the IPS uses 81.5 kg of xenon-133 as a propellant and the launch is delayed by 26.2 days, the amount of xenon-133 that would remain is __________ kg.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

7. The decay equation for xenon-133 is

A. ${}^{133}_{54}\text{Xe} \rightarrow {}^{133}_{54}\text{Xe} + \gamma$

B. ${}^{133}_{54}\text{Xe} \rightarrow {}^{129}_{52}\text{Te} + {}^{4}_{2}\alpha$

C. ${}^{133}_{54}\text{Xe} \rightarrow {}^{133}_{55}\text{Cs} + {}^{0}_{-1}\beta + \overline{v}$

D. ${}^{133}_{54}\text{Xe} \rightarrow {}^{133}_{53}\text{I} + {}^{0}_{-1}\beta + \overline{v}$

Scenario 4

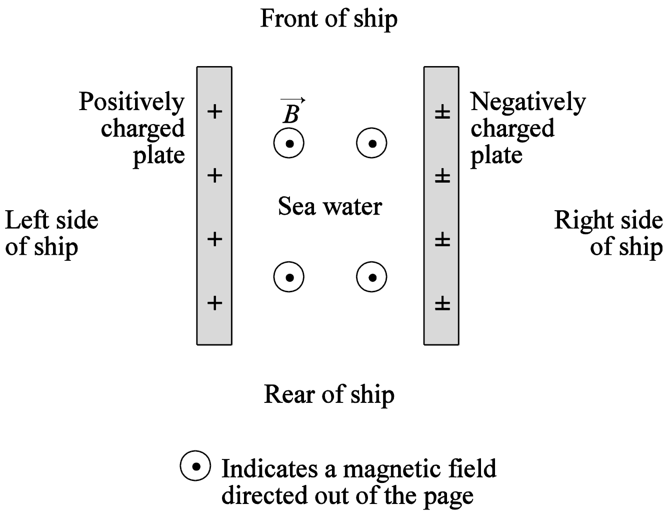
Use the following information to answer the next five questions.

In a type of propulsion called magnetohydrodynamic (MHD) propulsion, the magnetic force on moving charges is used to propel ships and submarines. Because there are no moving parts necessary for this type of propulsion, a vessel using this system could navigate without producing noise and, so, would be very hard to locate.

This propulsion system uses perpendicular magnetic and electric fields and the charges present in seawater. The seawater is expelled out the back of the system, thereby propelling the vessel forward.

When the seawater is at rest between the oppositely charged plates and the MHD propulsion system is turned on, the positively charged ions in the seawater (for example Na^+) and the negatively charged ions in the seawater, (for example Cl^-) accelerate toward the oppositely charged parallel plates. The magnetic field, which is perpendicular to both the ion motion and the electric field direction, deflects the path of the ions. The water is then forced toward the rear of the ship.

The diagram below shows a portion of an MHD thruster from the prototype ship Yamato 1.



Specifications for a Prototype MHD Thruster

Distance between plates	0.140 m
Electric potential difference between plates	170 V
Magnetic field intensity in region between plates	4.0 T

1. The direction of the uniform electric field created between the charged parallel plates shown in the diagram is toward the

   A. left side of the ship
   B. right side of the ship
   C. front of the ship
   D. rear of the ship

Numerical Response

2. The electric field strength between the positively charged and negatively charged parallel plates, expressed in scientific notation, is ***a.bc*** × 10^{d} N/C. The values of ***a***, ***b***, ***c***, and ***d*** are _____, _____, _____, and _____.

   (Record all **four digits** of your answer in the numerical-response section on the answer sheet.)'

3. *The direction of the electrostatic force on the positively charged ions is toward the __**i**__ of the ship. The direction of the electrostatic force on the negatively charged ions is toward the __**ii**__ of the ship. The direction of the magnetic force on the sodium ions is toward the __**iii**__ of the ship. The direction of the magnetic force on the chloride ions is toward the __**iv**__ of the ship.*

   The row that completes the four statements above is row

Row	***i***	***ii***	***iii***	***iv***
A.	left side	right side	front	front
B.	left side	right side	rear	rear
C.	right side	left side	front	front
D.	right side	left side	rear	rear

Numerical Response

4. At the moment when a sodium ion, Na^{+}, is moving with a velocity of 3.00 m/s perpendicular to the magnetic field, the magnetic force on the ion, expressed in scientific notation, is ***a.b*** × 10^{-cd} N. The values of ***a***, ***b***, ***c***, and ***d*** are _____, _____, _____, and _____.

   (Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Use the following additional information answer the next question.

An electrical current in a resistor heats the resistor. In a similar manner, the ion flow between the oppositely charged plates heats the seawater. A ship using an MHD propulsion system can be detected by this electromagnetic signature left in the seawater.

Every minute, 4.61×10^{20} singly charged ions pass through the MHD thruster.

Numerical Response

5. The ion current through the MHD thruster is equivalent to _______ A.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Scenario 5

Use the following information to answer the next seven questions.

There are many different types of propulsion engines for satellites. One type of ion propulsion thrust chamber and the satellite to which it is attached are described below.

The cylindrical thrust chamber of the engine has a central spike. Electromagnets are used to produce a non-uniform magnetic field directed radially toward the spike. A virtual cathode consisting of trapped electrons is located at the rear of the thrust chamber. An electric field exists between the anode and the virtual cathode.

Positive xenon ions enter the thrust chamber at the anode and accelerate toward the virtual cathode, which results in thrust on the satellite. As the xenon ions pass through the virtual cathode, they pick up electrons and neutral xenon atoms fly out of the chamber.

Diagram I: Thrust Chamber in Engine

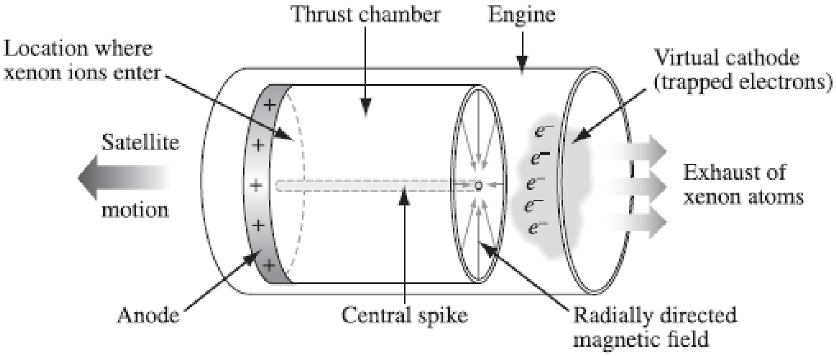
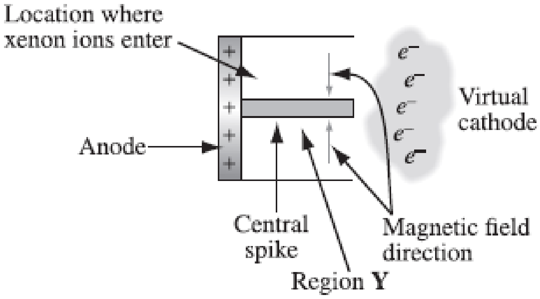


Diagram II: Cross Section of Thrust Chamber



Thrust Chamber Specifications

Magnetic field intensity at the location where the xenon ions enter	0.0200 T
Electric field intensity at the location where the xenon ions enter	1.00×10^4 V/m
Mass of one xenon ion, Xe+	2.19×10^{-25} kg
Exit speed of neutral xenon atom with respect to the thrust chamber	1.5×10^4 m/s

1. In diagram II on the previous page, the direction of the **electric field** in region Y is

   A. to the right
   B. to the left
   C. into the page
   D. out of the page

2. As the xenon ions, Xe+, move through region Y, as labelled in diagram II on the previous page, they experience both electric and magnetic forces. The direction of the **magnetic force** that they experience is

   A. into the page
   B. out of the page
   C. toward the top of the page
   D. toward the bottom of the page

3. The xenon ions, Xe+, enter the thrust chamber at a negligible speed. The minimum distance between the anode and the virtual cathode that is required to produce the exit speed is

   A. 1.2×10^{-16} m
   B. 1.0×10^{-6} m
   C. 1.5×10^{-2} m
   D. 1.4×10^{12} m

Numerical Response

4. While in the thrust chamber, a xenon ion experiences an impulse, expressed in scientific notation, of $a.b \times 10^{-cd}$ kg·m/s. The values of ***a***, ***b***, ***c***, and ***d*** are _____, _____, _____, and _____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Use the following information to answer the next question.

Xenon ions, m_{ion}, reach the virtual cathode with a speed of v_1. When a xenon ion collides with a stationary electron, m_e, in the virtual cathode, the xenon atom, m_{atom}, formed has a speed of v_2.

5. The relationship between v_2 and v_1 can be expressed as

A. $v_2 = \left(\frac{m_{\text{ion}} + m_e}{m_{\text{atom}}}\right)v_1$

B. $v_2 = \left(\frac{m_{\text{atom}}}{m_{\text{ion}} + m_e}\right)v_1$

C. $v_2 = \left(\frac{m_{\text{ion}}}{m_{\text{atom}}}\right)v_1$

D. $v_2 = \left(\frac{m_{\text{atom}}}{m_{\text{ion}}}\right)v_1$

Use the following additional information to answer the next two questions.

Ion Propulsion Engine and Satellite Specifications

Average thrust applied by the engine to the satellite	0.200 N
Mass of satellite and propulsion system	2.5×10^3 kg
Speed of xenon atom exiting the thrust chamber	1.5×10^4 m/s
Mass of xenon atom	2.19×10^{-25} kg

6. The length of time, in hours, that this type of ion propulsion engine must be in operation in order to increase the speed of the satellite and propulsion system by 12.0 m/s is

A. 0.0240 h
B. 41.7 h
C. 250 h
D. 1.50×10^5 h

7. The number of xenon atoms that would have to be discharged as exhaust in order to increase the speed of the satellite and propulsion system described above by 1.00 m/s is

A. 5.1×10^{19} atoms
B. 7.8×10^{21} atoms
C. 1.6×10^{22} atoms
D. 7.6×10^{23} atoms

Scenario 6

Use the following information to answer the next five questions.

The element ununquadium (${}^{289}_{114}\text{Uuq}$) has been created by fusing calcium ions (${}^{48}_{20}\text{Ca}$) with plutonium nuclei (${}^{244}_{94}\text{Pu}$).

The calcium ions are doubly charged (+2*e*) and have a mass of 7.96×10^{-26} kg. To accelerate these ions to a high enough energy to fuse with plutonium, they are repeatedly accelerated by an electric potential difference. They are contained in a magnetic field between these accelerations.

In one stage of the acceleration process, calcium ions enter the accelerating chamber at a speed of 1.00×10^{6} m/s and exit it at a speed of 2.75×10^{6} m/s. They immediately enter a magnetic field and follow a path that has a radius of 1.24 m.

1. Which of the following equations could be the nuclear reaction equation for the fusion of calcium and plutonium in the production of ununquadium?

   A. ${}^{48}_{20}Ca + {}^{244}_{94}Pu \rightarrow {}^{289}_{114}Uuq + {}^{4}_{2}\alpha$
   B. ${}^{48}_{20}Ca + {}^{244}_{94}Pu \rightarrow {}^{289}_{114}Uuq + 3\,{}^{0}_{-1}\beta + \bar{\nu}$
   C. ${}^{48}_{20}Ca + {}^{244}_{94}Pu \rightarrow {}^{289}_{114}Uuq + 3\,{}^{1}_{0}n$
   D. ${}^{48}_{20}Ca + {}^{244}_{94}Pu + 3\,{}^{1}_{0}n \rightarrow {}^{289}_{114}Uuq$

2. The electric potential difference in the accelerating chamber is

   A. 1.24×10^{5} V
   B. 1.52×10^{5} V
   C. 8.16×10^{5} V
   D. 9.38×10^{5} V

Numerical Response

3. The strength of the magnetic field used to contain the calcium ions, expressed in scientific notation, is ***a.bc*** $\times 10^{-d}$ T. The values of ***a***, ***b***, ***c***, and ***d*** are _____, _____, _____, and _____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Use the following additional information to answer the next two questions.

The decay chain of ununquadium-289 is shown below.

$$^{289}_{114}\mathrm{Uuq} \rightarrow {}^{285}_{112}\mathrm{Uub} + \mathrm{X} \rightarrow {}^{281}_{110}\mathrm{Ds} + \mathrm{Y}$$

Ununquadium-289 has a half-life of 30.4 s.

4. The decay particles *X* and *Y* are

   A. both alpha particles
   B. both beta positive particles
   C. a beta positive particle and an alpha particle, respectively
   D. an alpha particle and a beta positive particle, respectively

5. If 1.00 μg of ununquadium-289 is initially produced, the mass of ununquadium-289 remaining after 1.00 min will be

   A. 0.255 μg
   B. 0.507 μg
   C. 0.703 μg
   D. 0.977 μg