OAKRIDGE ACADEMY OF SCIENCE & TECHNOLOGY
Department of Physics & Chemical Sciences
Problem Set #4: Integrated STEM
Course: AP Physics & Chemistry | Instructor: Dr. E. Vance

TOTAL POINTS: 100
Score: _____ / 100
Due: Oct 28, 2026

- **Calculators:** Scientific/graphing allowed (TI-84 style).
- **Show Work:** Full credit requires setup, values, and units.
- **Integrity:** Concepts may be discussed; work must be unique.
- **Submission:** Place in Bin B by 3:15 PM on due date.

1 Section I: Multiple Choice & Conceptual Analysis (20 Points)

Select the best response for each item. Encircle your choice and write a brief 1-sentence justification.

Q1. A monochrome beam of green laser light ($\lambda = 532$ nm) transitions from air ($n = 1.00$) into crown glass ($n = 1.52$). Which statement correctly describes the change in the wave's properties?

(A) The frequency decreases, while the wavelength remains constant.
(B) The frequency remains constant, while the wavelength decreases to approximately 350 nm.
(C) The speed increases to 4.56×10^8 m/s, and frequency increases.
(D) Both speed and frequency decrease by a factor of 1.52.

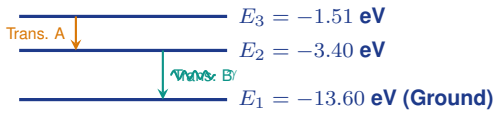
Justification: _____

Q2. A 2.50 kg aluminum block ($90.0°$C) is placed into 1.00 kg of water ($20.0°$C) in an insulated calorimeter. What is the equilibrium temperature T_f? ($c_{\text{Al}} = 900$ J/(kg $\cdot°$ C), $c_{\text{w}} = 4184$ J/(kg $\cdot°$ C)).

(A) $35.0°$C (B) $44.5°$C (C) $55.0°$C (D) $68.2°$C

Justification: _____

Q3. Refer to the energy level schematic for synthetic atom **Vertex-9**. A photon of frequency $f = 6.18 \times 10^{14}$ Hz is emitted during electronic relaxation.



Which quantum transition generated this emitted photon?

(A) $E_3 \to E_2$ (B) $E_2 \to E_1$ (C) $E_3 \to E_1$ (D) $E_1 \to \infty$

Justification: _____

Q4. The synthesis of ammonia ($N_2 + 3H_2 \rightleftharpoons 2NH_3$) has $E_a = 145$ kJ/mol. When a catalyst (**Nexa Corp**) is added:

(A) $\Delta H°$ becomes more negative.
(B) Both forward and reverse E_a are lowered by equal energy amounts.
(C) The equilibrium yield of NH_3 increases at constant temperature.
(D) Forward E_a decreases while reverse E_a increases.

Justification: _____

2 Section II: Structured Quantitative Problems (45 Points)

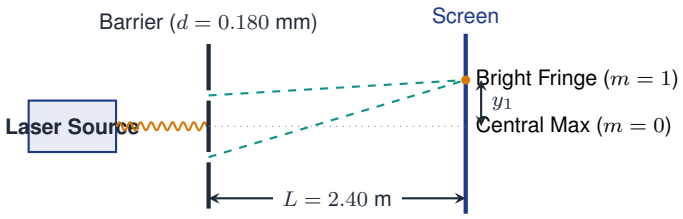
Wave Mechanics:
$v = f\lambda$ | $d\sin\theta = m\lambda$
$n_1 \sin\theta_1 = n_2 \sin\theta_2$

Thermodynamics:
$Q = mc\Delta T$ | $Q = n\Delta H$
$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

Constants:
$c = 3.00 \times 10^8$ m/s
$h = 6.626 \times 10^{-34}$ J · s | $R = 8.314$ J/(mol · K)

Problem 5: Optics & Wave Interference Analysis (20 Points)

A double-slit experiment is set up with a red laser ($\lambda = 632.8$ nm). The slit separation is $d = 0.180$ mm and the distance to the screen is $L = 2.40$ m.



a) Calculate the angular displacement θ_1 (in degrees) for the first-order bright fringe ($m = 1$).

b) Determine the distance y_1 on the screen from the central maximum to the first bright fringe.

c) If submerged in water ($n = 1.333$), calculate the new fringe spacing y_1' and explain the physical cause.

Solution Workspace (Show all steps, formulas, and units)

Problem 6: Calorimetry & Chemical Enthalpy (25 Points)

A chemist at **Synapse Materials Research** conducts a bomb calorimetry experiment to determine the molar heat of combustion of liquid ethanol (C_2H_5OH). A 1.84 g sample is ignited in a calorimeter containing 1200 g of water.

Reaction equation:

$$C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)$$

The system temperature rises from 22.40°C to 33.15°C. The bomb calorimeter heat capacity is $C_{\text{calorimeter}} = 850$ J/°C.

Experimental Dataset Summary

Parameter	Symbol / Variable	Recorded Value
Mass of Ethanol Sample	m_{ethanol}	1.84 g
Molar Mass of Ethanol	M_{ethanol}	46.07 g/mol
Mass of Water Bath	m_{water}	1200 g
Specific Heat of Water	c_{water}	4.184 J/(g $\cdot^\circ$ C)
Calorimeter Heat Capacity	$C_{\text{calorimeter}}$	850 J/°C
Initial Temperature	T_i	22.40°C
Final Temperature	T_f	33.15°C

a) Calculate the total thermal energy Q_{total} absorbed by the water bath and calorimeter vessel.

b) Calculate the number of moles of ethanol consumed in this reaction trial.

c) Determine the experimental molar enthalpy of combustion (ΔH_{comb}) in kJ/mol with proper sign.

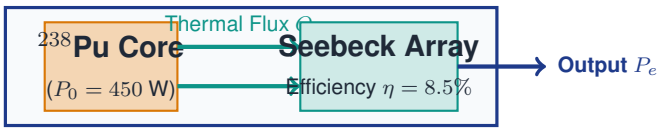
d) Given accepted $\Delta H^\circ_{\text{comb}} = -1367$ kJ/mol, calculate the experimental percent error.

Solution Workspace (Show all steps, formulas, and units)

3 Section III: Advanced Free-Response Design Challenge (35 Points)

Scenario: Photovoltaic-Thermal Hybrid Cell for Space Probes

Engineers at **Nimbus Clean Energy Labs** are evaluating a radioisotope thermal generator (RTG) coupled with a thermoelectric Seebeck array to produce electricity from the decay heat of Plutonium-238 (^{238}Pu).



Part A: Radioactive Decay Kinematics (12 Points)

Plutonium-238 decays via alpha particle emission (α) with half-life $T_{1/2} = 87.7$ years: $^{238}_{94}\text{Pu} \longrightarrow {}^{A}_{Z}\text{X} + {}^{4}_{2}\text{He}$.

1. Identify daughter nuclide $^{A}_{Z}$X (atomic number Z, mass number A, chemical symbol).
2. Calculate the decay constant λ of Plutonium-238 in s^{-1}.
3. Calculate remaining thermal power output after 25.0 years ($P_0 = 450$ W).

Solution Workspace (Show all steps, formulas, and units)

Part B: System Efficiency & Power Conversion (13 Points)

1. Given $\eta = 8.50\%$, calculate initial electrical power output P_e (Watts) at $t = 0$.
2. Telemetry requires minimum continuous power 28.0 W. Calculate lifespan in years before dropping below threshold.

Solution Workspace (Show all steps, formulas, and units)

Part C: Conceptual Synthesis & Design Evaluation (10 Points)

Explain two physical mechanisms causing RTG system power output to degrade faster than radioisotope decay kinetics predict.

Solution Workspace (Show all steps, formulas, and units)

— END OF PROBLEM SET #4 —