(1) Short Answers

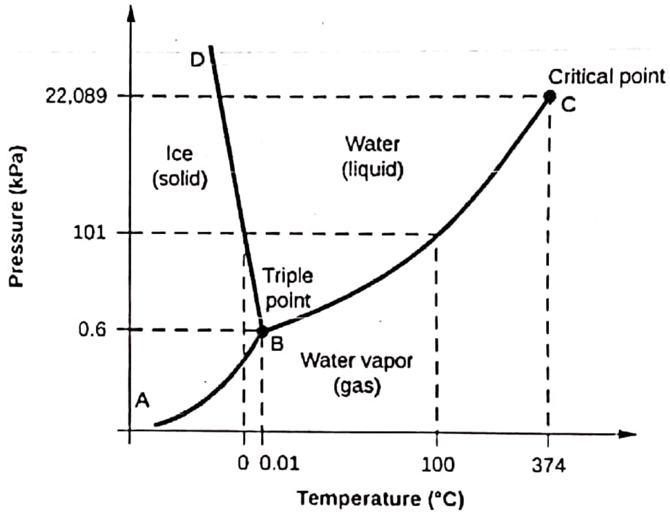
a) You are given that water is at 10 MPa and 311 °C. Can you define its state? Why or why not?

No, you cannot define its state because P & T are dependent properties for a saturated mixture.

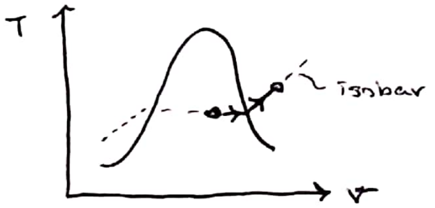
The state postulate requires 2 independent, intensive properties to define a state.

b) The phase diagram for water is shown here. What unique feature enables glaciers to travel across the ground and carve landscapes? *Reminder:* Glaciers can move because ice at the bottom melts.

The solid-liquid line is negatively sloped meaning that an increase in pressure at T = 0°C will melt the ice at the bottom of the glacier where pressure is highest.



c) Water that is a saturated mixture is expanded at constant pressure to a superheated vapor state. Sketch this process as a solid line on a T-v diagram including any relevant isotherms or isobars as dashed lines. Is the final water temperature higher, lower, or the same as its initial temperature?



The final water temperature is higher than the initial temperature.

d) A rigid helium tank at room temperature, 20 °C, is transported to a summer birthday. It reaches a temperature of 50 °C when left in a parked car while the driver picks up additional party supplies. What is its change in specific internal energy, Δu?

$T_1 = 20°C$

$T_2 = 50°C$

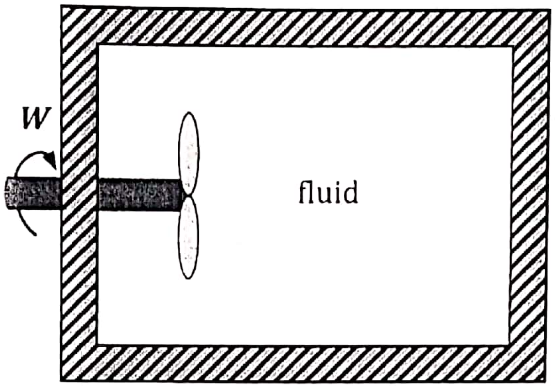
$\Delta u = c_v \Delta T$

$= 3.1156(30) = 93.468 \text{ kJ/kg}$

assume Helium is an ideal gas w/ constant specific heats

(2) *Rigid Vessel Work*

A 0.1 m^3 insulated, rigid vessel has a propeller which does 1 MJ of work on the fluid contained within.



If the fluid temperature and pressure are initially 20 °C and 100 kPa respectively, what is the change in specific internal energy, Δu, caused by the work interaction from the propeller rotation if the fluid is:

a) water

$P_{sat}(20°C) = 2.34$ kPa $< P_1$ ∴ subcooled liquid $\rightarrow v_1 = v_f(T) = .001002\ m^3/kg$

* could also use $\rho = 1000\ kg/m^3$ & $v = 1/\rho$

$u_1 = u_f(T) = 83.913\ kJ/kg$

$u_2 = 93.933\ kJ/kg$
(unnecessary for this part)

$\Delta U = \cancel{Q}_{12} - W_{12} = W_{in} = 1 MJ$
$= m(u_2 - u_1) = \forall/v\,(u_2 - u_1)$
$= .1/.001002\ \Delta u \rightarrow \Delta u = 10.02\ kJ/kg$

b) air *(assumed to be an ideal gas with constant specific heats)*

$v_1 = RT_1/P_1 = .287(293)/(100) = 0.84\ m^3/kg$

$\Delta U = W_{in} = 1 MJ = m(u_2 - u_1) = \forall/v\,(u_2 - u_1) = .1/.84\ \Delta u$
$\rightarrow \Delta u = 8409.1\ kJ/kg$

additionally,
$\Delta U = mc_v(T_2 - T_1) = \forall/v\ c_v(T_2 - T_1)$
$= (.119)(.718)(T_2 - T_1)$ (unnecessary for this part)

c) Comment on the differences between the two.

The increase in total internal energy is the same for both but because the mass of air is much less, its specific internal energy change is much greater

How would you determine the temperature and pressure after this process for the two different fluids? You do NOT need to calculate P_2 and T_2. We are asking you to describe your process for finding them. Specifically, given what you know about State 2, what resources and/or equations would you use?

d) water from above, u_2 & $v_2 = v_1$ are known so we can determine T_2 & P_2 from the steam tables

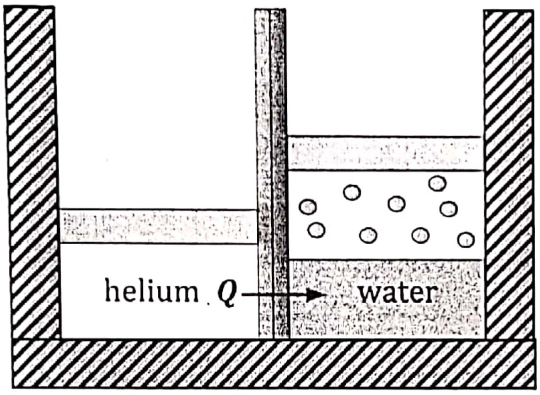
e) air *(assumed to be an ideal gas with constant specific heats)*

from above $\Delta U = mc_v \Delta T$ so we can find T_2
we also know $v_1 = v_2 \rightarrow Pv = RT \rightarrow P_2 = RT_2/v_2$

(3) Piston-Cylinder Heat Transfer

6 kg of helium gas is compressed isothermally in a piston-cylinder device from State 1 at $T_1 = 400$ K and $P_1 = 1$ atm to State 2 with a total volume that is one tenth of the initial volume, $V_2 = V_1/10$ m³.

A mixture of liquid and vapor water at 100 °C and $x_1 = 0.26$ is used to absorb the heat generated from the isothermal compression process. After heat transfer from the piston-cylinder of helium, the final state of the water is a saturated vapor. Determine the total mass [kg] of water that vaporizes during the process.



There is no heat transfer with the environment. Treat helium as an ideal gas with $R = 2.0769$ kJ/kg·K.

Helium (ideal gas)

$m = 6$ kg, $T_1 = 400$K, $P_1 = 1$atm

$\forall_2 = \forall_1/10$ m³ → $v_2 = v_1/10 = .823$ m³/kg

$T_2 = T_1$ (isothermal)

$v_1 = RT_1/P_1 = (2.0769)(400)/(101) = 8.23$ m³/kg

$P_2 = RT_2/v_2 = RT_1 10/v_1 = 10P_1 = 1010$ kPa

$\Delta U = Q_{12} - W_{12}$

for i.g. $u = u(T) \therefore \Delta U = 0$

$Q_{12} = W_{12} = \int_1^2 P\,d\forall$

$P\forall = mRT \rightarrow P = mRT/\forall$

$Q_{12} = W_{12} = \int_1^2 mRT/\forall\,d\forall = mRT\int_1^2 1/\forall\,d\forall$

$= mRT[\ln(\forall_2) - \ln(\forall_1)] = mRT\ln(\forall_2/\forall_1)$

$= (6)(2.0769)(400)\ln(1/10)$

$= -11{,}477.4$ kJ from helium to water

Water (NOT ideal gas)

$T_1 = 100°C = T_2$ → $P_1 = P_2 = P_{sat}(T) = 101.42$kPa

$x_1 = 0.26$

$x_2 = 1$ (saturated vapor)

$m = ?$

$v_1(T_1, x_1) = v_f + x_1(v_g - v_f)$

$= .001043 + .26(1.6720 - .001043)$

$= .4355$ m³/kg

$u_1(T_1, x_1) = u_f + x_1 u_{fg}$

$= 419.06 + .26(2087) = 961.68$ kJ/kg

OR $h_1 = h_f + x_1 h_{fg} = 1005.834$ kJ/kg

$v_2(T_2, x_2) = v_g(T_2) = 1.6720$ m³/kg

$u_2(T_2, x_2) = u_g(T_2) = 2506$ kJ/kg

OR $h_2 = h_g = 2675.6$ kJ/kg

$\Delta U = Q_{12} - W_{12}$

$m(u_2 - u_1) = Q_{12} - \int P\,d\forall$

$= Q_{12} - P(\forall_2 - \forall_1)$

$= Q_{12} - mP(v_2 - v_1)$

$\rightarrow Q_{12} = m((u_2 + Pv_2) - (u_1 + Pv_1))$

$m = Q_{12}\,(h_2 - h_1) = 6.87$kg

$m_{vap} = (1 - .26)m = 5.08$ kg