

PHYS 1220-02 Fall 2026 Quiz 3

Brief Solutions

1. Oven leaking heat to the kitchen

In this scenario, both the oven and the kitchen maintain their constant temperatures of 500 K and 280 K, respectively. Their entropy changes are then simply Q/T . The heat transfer Q is $(200 \text{ W})(40 \text{ min}) = 480 \text{ kJ}$.

A. Entropy change of the oven

The oven loses 480 kJ of heat at 500 K, so

$$\Delta S_o = (-480 \text{ kJ})/(500 \text{ K}) = -960 \text{ J/K}$$

B. Entropy change of the kitchen

The kitchen gains 480 kJ of heat at 280 K, so

$$\Delta S_k = (+480 \text{ kJ})/(280 \text{ K}) = +1684 \text{ J/K}$$

C. Entropy change of the universe

$$\Delta S = \Delta S_o + \Delta S_k = -960 \text{ J/K} + 1684 \text{ J/K} = 724 \text{ J/K}$$

2. Cooling tea

In this situation, the temperature of the tea is not constant. Its heat loss depends on its specific heat capacity c , mass m , and temperature drop ΔT by $dq = mc dT$. The formula for its entropy change then is

$$\begin{aligned} dS &= dq/T \\ &= mc dT/T \\ \Delta S &= \int dS = mc \int dT/T \\ &= mc \ln(T_f/T_i) \end{aligned}$$

To plug in the numbers, we first need to convert the temperatures to absolute temperatures: the formula depends on the ratio of the absolute temperatures, not on the difference between temperatures. The tea starts at $T_i = 92^\circ\text{C} = 365.15 \text{ K}$ and cools to $T_f = 70^\circ\text{C} = 343.15 \text{ K}$. Thus

$$\Delta S = mc \ln(T_f/T_i) = (0.800 \text{ kg})(4184 \text{ J}/(\text{kg} \cdot \text{K})) \ln(343.15/365.15) = -208 \text{ J/K}$$

The result is negative because heat leaves the tea.

3. Free expansion

Although we haven't learned a formula for the absolute multiplicity or entropy of an ideal gas sample, we do have a formula for the multiplicity *change* for a free expansion of an N -molecule ideal gas sample from volume V_i to V_f :

$$\frac{\Omega_f}{\Omega_i} = \left(\frac{V_f}{V_i}\right)^N$$

This yields

$$\Delta S = k_B \ln \left((V_f/V_i)^N \right) = k_B N \ln(V_f/V_i) = nR \ln(V_f/V_i)$$

Plugging in the numbers finds

$$\Delta S = (2.00 \text{ mol})(8.31441 \text{ J}/(\text{mol} \cdot \text{K})) \ln(4.2) = +23.9 \text{ J/K}.$$

4. Performance measures

A. For a heat pump, we want heat going into the warm side Q_h and the input is work W , so the performance measure is Q_h/W .

B. For a refrigerator, we want heat going out of the cold side Q_c and the input is work W , so the performance measure is Q_c/W .

C. For a heat engine, we want work produced W and the input is heat from the hot side Q_h , so the performance measure is W/Q_h .

5. Optimal heat pump temperature relationship

The performance measure for a heat pump is Q_h/W , and entropy constraints require that

$$\frac{Q_h}{W} \leq \frac{T_h}{T_h - T_c}.$$

Here, we learned that $Q_h/W = 12$, so

$$\begin{aligned} 12 &= \frac{T_h}{T_h - T_c} \\ 12 T_h - 12 T_c &= T_h \\ 12 T_h - T_h &= 12 T_c \\ 11 T_h &= 12 T_c \\ T_h &= \frac{12}{11} T_c \end{aligned}$$

6. Coulomb's constant

$$k = \frac{1}{4\pi\epsilon_0}$$

7. Coulombic interaction

Figuring out this problem involves a lot of conversions. Chief among these is finding the charge on the protons in one milligram of carbon-12.

First we find the number of protons. For that, we first need to find the number of moles of ^{12}C , then the number of atoms, then multiply that by 6 because there are 6 protons per atom.

$$10^{-6} \text{ kg } ^{12}\text{C} \cdot \frac{1 \text{ mol } ^{12}\text{C}}{0.012 \text{ kg } ^{12}\text{C}} \cdot \frac{6.022 \times 10^{23} \text{ atoms } ^{12}\text{C}}{1 \text{ mol } ^{12}\text{C}} \cdot \frac{6 \text{ p}^+}{1 \text{ atom } ^{12}\text{C}} = 3.011 \times 10^{20} \text{ p}^+$$

Once we know the number of protons, we find their total charge by multiplying by the charge per proton.

$$Q = (3.011 \times 10^{20} \text{ p}^+)(1.602 \times 10^{-19} \text{ C/p}^+) = 48.2 \text{ C}$$

A. Type of interaction

The protons and electrons attract each other. This begs the question of how the protons are held together at one spot and the electrons at another given that the protons repel other protons, just as the electrons repel other electrons.

B. Magnitude of the interaction

The electrostatic force between two point charges is

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}.$$

In this scenario, $q_1 = +48.2 \text{ C}$, $q_2 = -48.2 \text{ C}$, and $r = 12.724 \times 10^6 \text{ m}$. To find the force, plug and chug.

$$F = \frac{1}{4\pi \cdot 8.854 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2)} \frac{-(48.2 \text{ C})^2}{(12.724 \times 10^6 \text{ m})^2} = 0.129 \text{ N}$$

C. Field midway

To find the field, we find the field at the field point due to the protons $\vec{E}_p$ and the field at the field point due to the electrons $\vec{E}_e$. Those are both vector values, so we must add them together as vectors. Fortunately, these are both in the same direction, toward the electrons and away from the protons. Furthermore, their magnitudes are the same, because the charges have the same absolute value and the distances are equal. This means

$$E = E_e + E_p = 2E_e = 2 \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} = 2 \frac{1}{4\pi\epsilon_0} \frac{48.2 \text{ C}}{(6.362 \times 10^6 \text{ m})^2} = 0.0214 \text{ N/C}$$

8. Charge distribution on a conductor

This problem has us use Gauss's law together with the principle that the electric field within a conductor is zero to find where the charge resides on the conductor.

A. Charge on the whole system

The conducting ball has a charge of $Q_1 = +2 \text{ nC}$ and the point charge inside its cavity has a charge of $Q_2 = -1 \text{ nC}$, which adds up to $+1 \text{ nC}$.

B. Charge just inside the outer skin

Because the field is zero at this Gaussian surface, the flux through it is zero. Thus, the total charge it encloses must also be zero.

We aren't asked for the charge residing on the outer skin until part G, but here we see that it must be $+1 \text{ nC}$. That's the only way that the surface of Fig. A can enclose $+1 \text{ nC}$ while the surface of Fig. B encloses zero charge.

C. Charge of the inner skin and cavity

This Gaussian surface is entirely within the conductor, so the electric field must be zero everywhere on it. The electric flux through it must also be zero. Gauss's law then requires that it enclose a net charge of zero.

D. Charge within the cavity

We don't need to infer anything from Gauss's law here; this surface encloses nothing but the central point charge of -1 nC .

E. Charge on the inner skin

There is -1 nC inside the inner skin and zero charge just outside it, so the skin itself must bear a charge of $+1\text{ nC}$.

F. Charge within the conductor

There is zero charge within the surfaces of Fig. B and Fig. C, so there cannot be any net charge between them. Thus, the net charge within the conductor is zero.

G. Charge on the outer skin

As explained above, there must be $+1\text{ nC}$ of charge right on the ball's outside surface.