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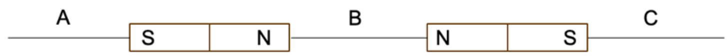
**I. [60 pts] Multiple Choice: Mark your answer on BOTH the bubble sheet and this page.**

1. [5 pts] Two identical bar magnets are arranged as shown at right. In which section of the horizontal axis connecting the magnets can the magnetic field be zero? The areas inside the magnets are excluded.




A. Section A

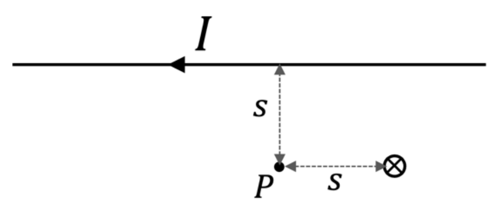
B. Section B

C. Section C

D. None of the above

**The two magnetic field contributions must point in opposite directions and be of equal magnitude. Only section B can contain such a point.**

2. [5 pts] Point $P$ is equidistant from two current carrying wires as shown at right. One of the wires carries a current to the left parallel to the page and the other wire carries the same amount of current, $I$, perpendicularly into the page. What is the magnitude of the magnetic field at point $P$?




A. $B = \frac{\mu_o I}{\pi s}$

B. $B = \frac{\mu_o I}{2\pi s}$

C. $B = \frac{\mu_o I}{\sqrt{2}\pi s}$

D. $B = \frac{\sqrt{2}\mu_o I}{\pi s}$

E. $B = 0$

**Choice B correctly gives the magnitude of a single long current-carrying wire. However, in this case there are two contributions to the net magnetic field, and their directions are perpendicular to each other and have equal magnitude. The net result is choice B times the square-root of 2, which is choice C.**

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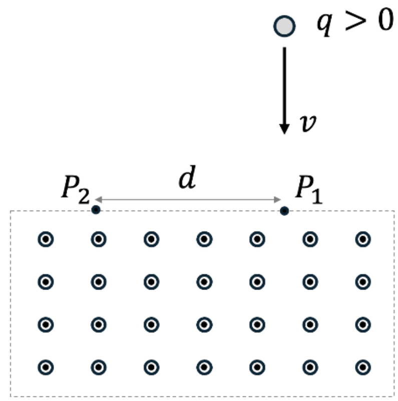
3. [5 pts] A particle of charge $q > 0$ and mass $m$ moves downward at velocity $v$ and enters a uniform magnetic field of strength B at point $P_1$ as shown at right. The magnetic field lines point out of the page. The charge exits the magnetic field at point $P_2$, which is on the same horizontal line with $P_1$. Determine the distance $d$ between points $P_2$ and $P_1$.




A. $d = \frac{mv}{qB}$

B. $d = \frac{mv}{2qB}$

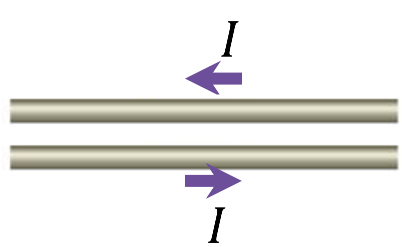
C. $d = \frac{\sqrt{2}mv}{qB}$

D. $d = \frac{2mv}{qB}$

E. $d = \frac{mv}{\sqrt{2}qB}$

**The trajectory of the particle will be a half circle with diameter 2r = d. Thus, the answer is double the radius of a particle's path in a magnetic field: d = 2r = 2mv/(qB).**

4. [5 pts] Two parallel wires carry current in opposite directions. Is there a force on the top wire due to the bottom wire, and if so in what direction is it?




A. There is no force.

B. There is a force out of the page.

C. There is a force into the page.

D. There is a force pointed downward.

E. There is a force up.

**By the right-hand rule for magnetic fields, the bottom wire produces a magnetic field that is out of the page at the top wire's location. Applying the right-hand rule for magnetic forces, a leftward current in an out-of-the-page magnetic field results in an upward magnetic force.**

5. [5 pts] The label on a candy bar says 400 Calories. Assuming that the efficiency for energy use by the body is 25%, if a 60 kg person were to use the energy in this candy bar to climb stairs, how high could the person go? (Note: $g = 9.8\ \mathrm{m/s^2}$)

   A. 330 m

   B. 710 m

   C. 950 m

   D. 2900 m

   E. 11000 m

**The candy bar contains 400 Cal = 1,674,400 J. At 100% efficiency, this amount of energy E would allow a height of h = E/mg = 2848 meters. But at 25% efficiency we could only go 25% as high, which is about 710 meters.**

6. [5 pts] The all-time highest temperatures recorded in Finland, Ireland, and the United States are as follows (according to Wikipedia). Finland: 37.2 °C, Ireland: 91.9 °F, United States: 330 K. Rank these countries from warmest to coldest in terms of the temperature record.

   A. Finland > Ireland > United States

   B. United States > Ireland > Finland

   C. Ireland > United States > Finland

   D. United States > Finland > Ireland

   E. Ireland > Finland > United States

**Convert all to Celsius:**
**USA: 330 K = 57°C**
**Ireland: 91.9°F = 33.3°C**
**Finland: 37.2°C**

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7. [5 pts] 500 J of work are done on a system in a process that decreases the system's thermal energy by 200 J. How much energy is transferred to ($Q > 0$) or from ($Q < 0$) the system as heat?

   A. $Q = 300$ J

   B. $Q = 700$ J

   C. $Q = -700$ J

   D. $Q = 200$ J

   E. $Q = -500$ J

**ΔE = Q + W, where W is the work done on the system.**
**Solving for Q, we find Q = ΔE – W = –200 J – 500 J = –700 J.**

8. [5 pts] A hot reservoir at temperature 576 K transfers 1050 J of heat to a cold reservoir at temperature 305 K. Find the change in entropy of the universe.

   A. 3.21 J/K

   B. 98.1 J/K

   C. 0.72 J/K

   D. 1.77 J/K

   E. 1.62 J/K

**The total entropy change can be found by adding the individual entropy changes:**
**ΔS for hot reservoir: Q/T = –1050 J / 576 K = –1.823 J/K**
**ΔS for cold reservoir: Q/T = +1050 J / 305 K = 3.443 J/K**

**The total is thus 1.62 J/K**

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9. [5 pts] A container has 1.0 gram of pure gaseous diatomic oxygen ($O_2$). A relevant portion of the periodic table is given. How many molecules of $O_2$ are in the container? (As shown in the diagram at right, the molar mass of atomic oxygen is 16 g/mol.)

| | | |
|---|---|---|
| | | 2 He 4.0 |
| 8 O 16.0 | 9 F 19.0 | 10 Ne 20.2 |
| 16 S 32.1 | 17 Cl 35.5 | 18 Ar 39.9 |

A. $1.9 \times 10^{22}$

B. $3.8 \times 10^{22}$

C. $7.5 \times 10^{22}$

D. $6.0 \times 10^{23}$

E. None of these are correct

**The molar mass of diatomic oxygen (32.0 g/mol) is twice that of atomic oxygen (16.0 g/mol). Thus, the number of moles n of the gas is (1 g) / (32.0 g/mol) = 1/32 moles. Multiplying by Avogadro's number gives the total number of particles.**

10. [5 pts] Container A has 5 moles of helium gas (monatomic) and container B has 5 moles of neon gas (monatomic). Both gases are at $-4°\mathrm{C}$. How do the total kinetic energies of the two samples of gas compare, or is it not possible to compare?

A. Container A (helium) has more total kinetic energy.

B. Container B (neon) has more total kinetic energy.

C. Both containers have equal total kinetic energy.

D. Impossible to determine since the pressures and volumes are not given.

**The temperature of a gas is directly proportional to its average kinetic energy. Thus, since the two samples have identical numbers of particles and identical temperatures, the must have identical total kinetic energies.**

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11. [5 pts] A sealed container of ideal gas undergoes an isothermal compression. Which of the following is true about the thermal energy of the gas and its and pressure?

A. Thermal energy remains the same, pressure increases.

B. Thermal energy remains the same, pressure decreases.

C. Thermal energy increases, pressure increases.

D. Thermal energy increases, pressure decreases.

E. None of these are completely correct.

**An isothermal process has constant temperature, which implies its thermal energy also remains constant. The ideal gas law pV = nRT then implies that for constant n and T, a decrease in volume V ("compression") implies an increase in pressure p**

12. [5 pts] A medical experiment requires a tube of length 0.18 m to be heated from $20°\mathrm{C}$ to $60°\mathrm{C}$. For the experiment to function properly, the tube must not increase in length by more than 0.00010 m. What is the maximum possible coefficient of thermal expansion for the tube?

A. $9.3 \times 10^{-6}\,\mathrm{K}^{-1}$

B. $1.4 \times 10^{-5}\,\mathrm{K}^{-1}$

C. $2.8 \times 10^{-5}\,\mathrm{K}^{-1}$

D. $4.8 \times 10^{-5}\,\mathrm{K}^{-1}$

E. None of these are correct

**The linear thermal expansion equation ΔL = α L ΔT can be solved for α.**

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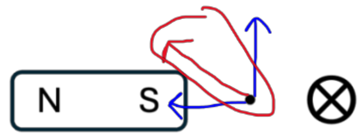
## II. Lecture long-answer questions (20 points total)

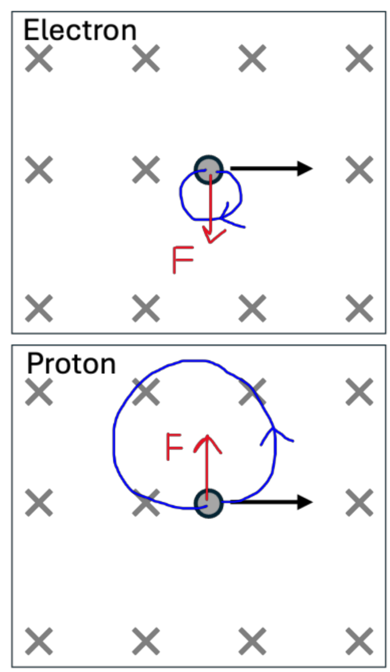
13. [5 pts] A long wire that carries current into the page is placed to the right of a bar magnet, as shown.




Determine the direction of the magnetic field directly between the wire and bar magnet. Assume the two sources produce magnetic fields of equal magnitude at the point of interest. Show your work and/or explain.

*The magnetic field due to the magnet is leftward (B-field points* <u>*into*</u> *the south pole). The magnetic field due to the current is upward (by the right-hand rule where thumb is conventional current and the fingers wrap around the circulating B-field). A superposition of leftward and upward magnetic fields produces a diagonal up-and-left net magnetic field.*

14. [5 pts] An electron and a proton move perpendicularly to identical uniform magnetic fields in the indicated directions at equal speeds. The mass of the electron is less than that of the proton.




In the diagrams at right, **sketch** the resulting trajectories for both the electron and proton. Your sketch should be qualitatively correct. **Explain** your reasoning.

*The radius of the resulting circular trajectory is $r = mv/(eB)$, so the smaller mass of the electron will result in a smaller radius.*

*By the right-hand rule for magnetic force on the proton at the instant shown, a rightward velocity and into-the-page magnetic field results in an* <u>*upward*</u> *magnetic force at the instant shown, hence a* <u>*counterclockwise*</u> *trajectory for the proton.*

*The direction of the trajectory for the electron is opposite (clockwise) because the centripetal force is opposite due to its negative charge.*

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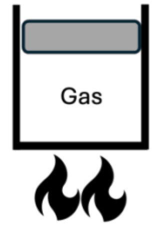
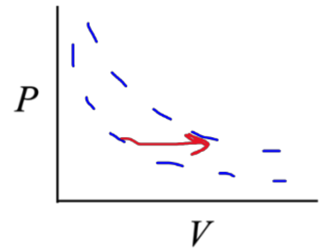
15. [5 pts] A flame is held underneath a sealed container of ideal gas. A piston that seals the top of the container is free to move up or down without friction. The temperature of the gas is observed to slowly increase.



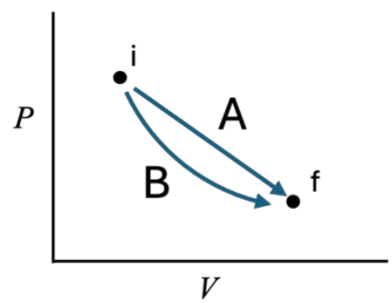

Sketch this process on the $PV$ diagram provided. Explain.

*The piston is free to move without friction, so the pressure remains constant. (If the pressure "tries" to change, the piston will move until it is again in the same equilibrium condition with atmospheric pressure that it was in before.) We are told that the temperature increases, so we must move in such a way that pressure is constant (horizontally) but temperature increases (reaches a 'higher' isotherm).*




16. [5 pts] The $PV$-diagram shows two different processes, A and B, connecting two states of a sample of ideal gas. The initial and final temperatures of the states are the same (i.e., $T_i = T_f$).

Is the heat added to the gas during process A *greater than, less than,* or *equal to* the heat added during process B, or is there *not enough information* to answer? Explain.




*Heat added to the gas is $Q = \Delta E_{th} - W_{on\ gas} = \Delta E_{th} + W_{by\ gas}$.*
*The changes in thermal energy of both processes are zero since the final temperatures are the same, so $Q = W_{by\ gas}$. Both processes have positive work done by the gas since volume is increasing (rightward on the diagram.) However, there is more work done by the gas in process A because there is a larger area between its path and the horizontal axis. Thus, process A has greater heat added to it.*

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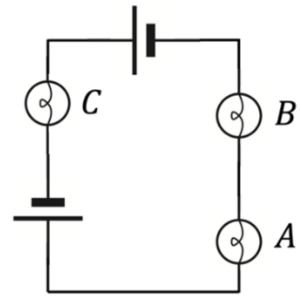
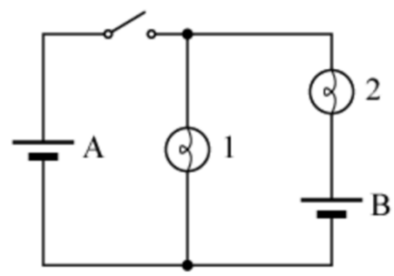
## III. Tutorial long answer questions (20 points total)

In the circuits in *Q*17 and *Q*18, all bulbs are identical, and all batteries are ideal and identical.




17. [5 pts] Rank the bulbs A-C according to brightness, from brightest to dimmest. Explain your reasoning.

    *The bulbs in the circuit at right are all connected in series (the order in which elements are connected in series does not impact the functioning of the circuit). Since the bulbs are connected in series, they all have equal brightness, A = B = C.*




18. [5 pts] After the switch is closed in the circuit at right, does the brightness of bulb 1 *increase*, *decrease*, or *stay the same*? Explain your reasoning.

    *Before the switch is closed, bulbs 1 and 2 are connected in series with battery B. Using Kirchoff's loop rule, the voltage across bulb 1 and 2 (before the switch is closed) is* $V_{bat}/2$.

    *When the switch is closed, the voltage across bulb 1 is equal to that across battery A. So, the voltage across bulb 1 increases from* $V_{bat}/2$ *to* $V_{bat}$. *An increase in voltage across the bulb will cause its brightness to increase.*

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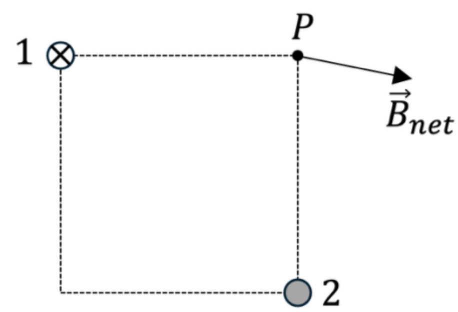
19. A long wire, wire 1, carries a current $I_0$ into the page. A second wire, wire 2, is located as shown. At point *P*, the net magnetic field points as shown (the wires are equidistant from point *P*).



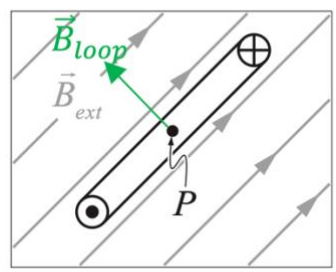

a) [3 pts] Does wire 2 carry a current into or out of the page? Explain.

*Using the RHR, wire 1 creates a field at point P that points downward. The net magnetic field at point P has both a downward and rightward component. The rightward component must be created by wire 2. A rightward magnetic field at point P is consistent with wire 2* ***carrying current into the page****.*

b) [3 pts] Is the current in wire 2 *greater than, less than* or *equal to* $I_0$? Explain.

***Greater than $I_0$.*** *Considering the direction of the net magnetic field in the figure above, the rightward component of the magnetic field is larger than that of the downward component. The wires are equidistant from point P, and since the rightward component is larger in magnitude than the downward and corresponds to the current through wire 2, the current through wire 2 is greater than that through wire 1.*

20. [4 pts] A small loop of wire is placed in a region with a uniform magnetic field $\vec{B}_{ext}$ that does not change with time. The loop is attached to a battery (not shown) so that there is a current through it as shown in the cross-sectional diagram at right. The center of the loop is at point *P*.




Note: The symbol ⊗ indicates current into the page and the symbol ⊙ indicates current out of the page.

Is the magnitude of the net magnetic field at point *P* *greater than, less than,* or *equal to* the magnitude of $\vec{B}_{ext}$? Explain your reasoning.

***Greater than****. Using the RHR for current loops, the magnetic field at the center of the loop ($\vec{B}_{loop}$) is up and to the left. The net magnetic field at point P is the vector sum of the $\vec{B}_{loop}$ and $\vec{B}_{ext}$. Since $\vec{B}_{loop}$ and $\vec{B}_{ext}$ are perpendicular, the magnitude of the net field is the Pythagorean sum of the two field magnitudes.*

$$|\vec{B}_{net}| = \sqrt{|\vec{B}_{loop}|^2 + |\vec{B}_{ext}|^2}$$

*This means that the magnitude of the net magnetic field at point P is both greater than $\vec{B}_{loop}$ and $\vec{B}_{ext}$.*

# 115 Equation Sheet: Final

## Physical Constants

Elementary charge: $e = 1.60 \times 10^{-19}$ C

Electron mass: $m_e = 9.11 \times 10^{-31}$ kg

Couloumb's constant:

$$K = \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9\,\mathrm{N \cdot m^2/C^2}$$

Permittivity of free-space:

$$\epsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2}$$

Permeability constant:

$$\mu_0 = 1.26 \times 10^{-6}\,\mathrm{T \cdot m/A}$$

Boltzmann's constant: $k_\mathrm{B} = 1.38 \times 10^{-23}\,\mathrm{J/K}$

Avogadro's number: $N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$

Gas constant: $R = 8.31\,\mathrm{J/mol \cdot K}$

Boltzmann-Stefan constant:

$$\sigma = 5.67 \times 10^{-8}\,\mathrm{W/(m^2 \cdot K^4}$$

## Unit Conversions

Electron volt: $1\text{ eV} = 1.60 \times 10^{-19}$ J

Calorie: $1\,\mathrm{Cal} = 4186\,\mathrm{J}$

## Helpful Equations from 114

Kinematics (constant acceleration):

$$x_f = x_i + (v_x)_i\Delta t + \tfrac{1}{2}a_x(\Delta t)^2$$

$$(v_x)_f = (v_x)_i + a_x\Delta t$$

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x\Delta x$$

Newton's 2nd Law: $\vec{a} = \dfrac{\vec{F}_\mathrm{net}}{m}$

Weight (Gravitational Force): $F_g = mg$

Work: $W = F_\parallel d = Fd\cos\theta$

Work-Energy Theorem: $\Delta E_{mech} = W$

Kinetic Energy: $K = \frac{1}{2}mv^2$

Gravitational Potential Energy: $U_g = mgy$

Power: $P = \dfrac{\Delta E}{\Delta t}$

Momentum: $p = mv$

## Chapter 20:

Coulomb's Law: $F_{1\text{ on }2} = F_{2\text{ on }1} = \dfrac{K|q_1||q_2|}{r^2}$

Electric field: $\vec{E} = \dfrac{\vec{F}_\mathrm{on\,q}}{q}$

Electric field for a point charge: $E = \dfrac{K|q|}{r^2}$

Electric field in a parallel-plate capacitor:

$$E = \frac{Q}{\epsilon_0 A}$$

## Chapter 21:

Electric Potential Energy: $U_{elec} = qV$

Electric Energy Conservation:

$$\Delta E = \Delta K + \Delta U_{elec}$$

Electric Potential of a Point Charge: $V = \dfrac{Kq}{r}$

Capacitance: $C = \dfrac{\epsilon_0 A}{d} = \dfrac{Q}{\Delta V_C}$

Energy stored in a capacitor: $U_C = \frac{1}{2}C(\Delta V_C)^2$

Electric Field inside a parallel-plate capacitor:

$$E = \frac{\Delta V_C}{d}$$

## Chapter 22:

Current: $I = \dfrac{\Delta q}{\Delta t}$

Resistance: $R = \dfrac{\rho L}{A}$

Ohm's Law: $I = \dfrac{\Delta V}{R}$

Power dissipated across a resistor:
$$P_R = I\Delta V_R = I^2 R = \frac{(\Delta V_R)^2}{R}$$

Batteries in series: $\Delta V_{\text{total}} = \mathcal{E}_1 + \mathcal{E}_2 + \mathcal{E}_3 + ...$

## Chapter 23:

Kirchoff's Loop rule: $\sum \Delta V = 0$

Kirchoff's Junction rule: $\sum I_{in} = \sum I_{out}$

Equivalent resistance:

Series: $R_{eq} = R_1 + R_2 + R_3...$

Parallel: $R_{eq} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...\right)^{-1}$

Equivalent capacitance:

Series: $C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...\right)^{-1}$

Parallel: $C_{eq} = C_1 + C_2 + C_3 + ...$

RC Time Constant: $\tau = RC$

Current in an RC Circuit:
$$I = I_0 e^{-t/\tau}$$

Potential in an RC Circuit:

Charging: $V_C = (V_C)_0(1 - e^{-t/\tau})$

Discharging: $V_C = (V_C)_0 e^{-t/\tau}$

## Chapter 24:

Magnetic field due to:

Long straight wire: $B = \frac{\mu_0 I}{2\pi r}$

Current loop: $B = \frac{\mu_0 I}{2R}$

Solenoid: $B = \frac{\mu_0 N I}{L}$

Force on moving charge: $F = |q|\, vB\sin\alpha$

Force on current-carrying wire: $F = ILB\sin\alpha$

Circular motion radius for charge in magnetic field: $r = \frac{mv}{|q|\, B}$

## Chapter 11:

Efficiency: $e = \frac{\text{what you get}}{\text{what you had to pay}} = \frac{W_{\text{out}}}{Q_{\text{H}}}$

Maximum efficiency: $e_{\max} = 1 - \frac{T_{\text{C}}}{T_{\text{H}}}$

Fahrenheit conversion: $T(°C) = \frac{5}{9}[T(°F) - 32°]$

Kelvin conversion: $T(K) = T(°C) + 273$

First law of thermodynamics: $\Delta E_{\text{th}} = W + Q$

Entropy change at constant temp.: $\Delta S = \frac{Q}{T}$

Entropy change of universe: $\Delta S_{\text{univ}} > 0$

## Chapter 12:

Number of moles: $n = \frac{M(\text{in grams})}{M_{\text{mol}}}$

Thermal energy: $E_{\text{th}} = \frac{3}{2} k_B N T$

rms speed: $v_{\text{rms}} = \sqrt{\frac{3k_{\text{B}}T}{m}}$

Pressure: $p = \frac{F}{A}$

Ideal gas law: $pV = Nk_{\text{B}}T = nRT$

Volume thermal expansion: $\Delta V = \beta V_{\text{i}} \Delta T$

Linear thermal expansion: $\Delta L = \alpha L_{\text{i}} \Delta T$

Specific heat: $Q = Mc\Delta T$

Heat of transformation: $Q = \pm ML$

Molar specific heat:

at constant volume: $Q = nC_{\text{V}}\Delta T$

at constant pressure: $Q = nC_{\text{P}}\Delta T$

Conduction: $\frac{Q}{\Delta t} = \left(\frac{kA}{L}\right)\Delta T$

Radiation: $\frac{Q}{\Delta t} = e\sigma A T^4$