Name: ______________________

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Due Date: ______________________

B.1 Thermal Energy Transfers

Understandings

- Molecular theory in solids, liquids, and gases.
- Density ρ as given by $\rho = \frac{m}{V}$.
- Kelvin and Celsius scales are used to express temperature.
- The change in temperature of a system is the same when expressed with the Kelvin or Celsius scales.
- The internal energy of a system is the total intermolecular potential energy arising from the forces between the molecules plus the total random kinetic energy of the molecules arising from their random motion.
- Temperature difference determines the direction of the resultant thermal energy transfer between bodies.
- A phase change represents a change in particle behavior arising from a change in energy at constant temperature.
- Quantitative analysis of thermal energy transfers Q with the use of specific heat capacity c and specific latent heat of fusion and vaporization of substances L as given by $Q = mc\Delta T$ and $Q = mL$.
- Conduction, convection, and thermal radiation are the primary mechanisms for thermal energy transfer.
- Conduction in terms of the difference in the kinetic energy of particles.
- Quantitative analysis of rate of thermal energy transfer by conduction in terms of the type of material and cross-sectional area of the material and the temperature gradient as given by $\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$.
- Qualitative description of thermal energy transferred by convection due to fluid density differences.
- Quantitative description of thermal energy transferred by convection due to fluid density differences.
- Quantitative analysis of energy transferred by radiation as a result of the emission of electromagnetic waves from the surface of a body, which in the case of a black body can be modeled by the Stefan-Boltzmann law as given by

$L = \sigma A T^4$ where L is the luminosity, A is the surface area, and T is the absolute temperature of the body.

- The concept of apparent brightness b.
- Luminosity L of a body as given by $b = \frac{L}{4\pi d^2}$.
- The emission spectrum of a black body and the determination of the temperature of the body using Wien's displacement law as given by $\lambda_{\max} T = 2.9 \times 10^{-3}$ mK where $\lambda_{\max}$ is the peak wavelength emitted.

Equations

$$\rho = \frac{m}{V}$$

$$\overline{E_{\mathrm{k}}} = \frac{3}{2} k_{\mathrm{B}} T$$

$$Q = mc\Delta T$$

$$Q = mL$$

$$\frac{\Delta Q}{\Delta t} = kA \frac{\Delta T}{\Delta x}$$

$$L = \sigma A T^4$$

$$b = \frac{L}{4\pi d^2}$$

$$\lambda_{\max} T = 2.898 \times 10^{-3} \text{ mK}$$

If you are interested in learning more about thermal physics then please read the book *Concepts in Thermal Physics* by Stephen J. Blundell and Katherine M. Blundell.

Visiting the coldest town in the world - Chilling Out | 60 Minutes Australia
60 Minutes Australia
https://www.youtube.com/watch?v=l1noUh2NrLI

The hottest place on Earth | 60 Minutes Australia
60 Minutes Australia
https://www.youtube.com/watch?v=bdeOZ6rJ36Q

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: Define *solid*. What are its characteristics?

2. C: Define *fluid.*

3. C: Define *liquid*. What are its characteristics?

4. C: Define *gas*. What are its characteristics?

5. C: Define and give the units for each variable for density $\rho = \frac{m}{V}$. Is it a scalar or vector? Do not confuse density ρ with power P or momentum $\vec{p}$ or pressure p!

6. E: Determine the volume of a 1.00 kg gold bar if gold has a density of approximately 19,300 kg/m^3.

7. C: Define *diffusion.*

8. C: Which state of matter has the most potential energy: a solid, a liquid, or a gas?

9. C: Define *temperature.*

10. C: Define *Degrees Celsius*. What is the melting point and the boiling point of water in *degrees Celsius*?

11. C: Define *Kelvin*. What is the melting point and the boiling point of water in Kelvin?

12. C: Define *absolute zero.*

13. C: Which has greater kinetic energy: 0 °C ice or 0 °C water? Which has greater potential energy?

14. C: Define and give the units for each variable of the equation for *Boltzmann's constant* $k_{\mathrm{B}} = \frac{R}{N_{\mathrm{A}}}$.

15. C: Define and give the units for each variable for the equation for the internal energy of an ideal gas $\overline{E_{\mathrm{k}}} = \frac{3}{2} k_{\mathrm{B}} T = \frac{3}{2} \frac{R}{N_{\mathrm{A}}} T$.

16. C: Define *thermal equilibrium.*

17. C: Define *heat.*

18. C: Define *internal energy.*

19.C: Define *phase change*.

20.C: What does the equation $Q = mc\Delta T$ tell us? Define and give the units of each variable.

21.C: Define *melting*. Does an object gain potential energy or lose potential energy when it melts? What about kinetic energy?

22.C: Define *freezing*. Does an object gain potential energy or lose potential energy when it freezes? What about kinetic energy?

23.C: Define *vaporization/boiling*. Does an object gain potential energy or lose potential energy when it vaporizes/boils? What about kinetic energy?

24.C: Define *condensation*. Does an object gain potential energy or lose potential energy when it condenses? What about kinetic energy?

25.C: What does the equation $Q = mL_{\mathrm{f}}$ tell us? Define and give the units of each variable.

26.C: What does the equation $Q = mL_{\mathrm{v}}$ tell us? Define and give the units of each variable.

27.E: Moses has 500 grams of gold.

a. Go online to find the specific heat capacity of gold in its solid state in $\frac{\text{J}}{\text{kg}\times\text{K}}$.

b. How much energy will it take to increase the temperature of solid gold by 50°C?

c. How much energy will be lost by solid gold if its temperature decreases by 50°C?

28.E: How much energy will be needed to increase the temperature of 0.8 kg of solid ice from minus 30°C to steam at plus 140°C? Draw a temperature vs. energy graph of this process.

$c_{\text{solid}} = 2{,}108\ \frac{\text{J}}{\text{kg}\times\text{K}}$	$c_{\text{liquid}} = 4{,}186\ \frac{\text{J}}{\text{kg}\times\text{K}}$	$c_{\text{gas}} = 1{,}996\ \frac{\text{J}}{\text{kg}\times\text{K}}$
$L_{\text{f}} = 3.34\times10^{5}\ \frac{\text{J}}{\text{kg}}$	$L_{\text{v}} = 2.26\times10^{6}\ \frac{\text{J}}{\text{kg}}$	

29. E: Approximately how much energy will be needed to melt 1.25 kg of silver which is at a room temperature of 22.0 °C? The specific heat capacity of silver is approximately $236\ \frac{\text{J}}{\text{kg}\times°\text{C}}$, the latent heat of vaporization of silver is approximately 2.51×10^5 J, and the melting point of silver is approximately 962 °C.

30. E: Aaron drops a 6.00 kg gold block with a temperature of 20.0°C into a tub with 2.00 kg of liquid water at 90.0°C. What will be the final temperature of the system?

31.E: A ball of copper, which has a specific heat capacity of $c = 390.\frac{\text{J}}{\text{kg°C}}$, has a mass of 165 grams and is initially at a temperature of 115°C. This ball is quickly inserted into an insulated cup containing 125 ml of water at a temperature of 22.0°C.

a. What will be the final, equilibrium temperature of the ball and the water?

b. How much heat did the copper ball lose to the water?

c. How much heat did the water gain from the ball?

32.C: Define *conduction, convection,* and *radiation.* Give an example of each.

33.C: What is the difference between a *thermal conductor* and *thermal insulator*? Give an example of each.

34.C: Describe the equation $\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta x}$.

35.E: A silver plate 3.00 cm thick has a cross-sectional area of $4{,}000.\ \mathrm{cm}^2$. One face is at 160.°C and the other is at 130.°C. How much heat passes through the plate each second? For silver, $k = 406\ \frac{\mathrm{W}}{\mathrm{mK}}$.

36.E: A metal plate 6.00 mm thick has a temperature difference of 48.0°C between its faces. It transmits 200. kcal/h through an area of $7.00\ \mathrm{cm}^2$. Calculate the thermal conductivity of this metal in $\frac{\mathrm{W}}{\mathrm{mK}}$.

37.E: Two metal plates are soldered together. It is known that $A = 70.0\ \text{cm}^2$, $L_1 = 2.00$ mm, $L_2 = 4.00$ mm, $T_1 = 110.$ °C, and $T_2 = 20.0$°C. For the plate on the left $k_1 = 45.0\ \frac{\text{W}}{\text{mK}}$ and for the plate on the right $k_2 = 85.0\ \frac{\text{W}}{\text{mK}}$. Determine the temperature of the soldered junction in K and the heat flow rate in J/s.

38.C: Define *absorb*, *reflect* and *emit.*

39.C: Define *black body.*

40.C: State the definition, equation, and units for *emissivity*. What is the *emissivity* of a really dark colored object? What is the *emissivity* of a really light colored object?

41.C: Define *luminosity L*. Units?

42.C: What does the *Stefan-Boltzmann law* tell us? State the equation and define each variable in the *Stefan-Boltzmann law*.

43.E: A spherical body of 5.00 cm in diameter is maintained at 700.°C. Assuming that it radiates as if it were a blackbody, at what rate (in Watts) is energy radiated from the sphere?

44.E: The average surface temperature of the Sun is 5.778×10^3 K and its average radius is 6.957×10^8 m. Assuming that it radiates as if it were a blackbody, at what rate (in Watts) is energy radiated from the sphere?

45.E: The radius of star X is four times that of star Y and its temperature is three times that of Y. Find the ratio of luminosity of Y to that of X.

46.E: A blackbody has a surface area of 4.00 m^2 and temperature of 450. K. The blackbody is in a closed room with room temperature of 293 K. How much energy does the blackbody lose per minute?

47.C: Define *apparent brightness b*. Units? What is the mathematical relationship between *apparent brightness b* and *luminosity L*?

48.E: The luminosity of the Sun is 3.846×10^{26} W and its distance from the Earth is about 1.50×10^{11} m. Determine the apparent brightness *b* of the Sun.

49.E: The apparent brightness of star X as observed from Earth is three times greater than that of star Y as observed from Earth. The luminosity of star X is two times greater than that of star Y. Determine the ratio of the distance of star Y to Earth to that of star X to Earth.

50.C: What does *Wien's displacement law* tell us? State the equation and define each variable for *Wien's displacement law*. Draw and label a graph describing *Wien's displacement law*.

51.E: The Sun emits electromagnetic waves with a maximum wavelength of 570. nm. According to this information what is the surface temperature of the Sun?

52.E: The maximum surface temperature of the red supergiant Betelgeuse is approximately 3.80×10^3 K. Determine the maximum wavelength emitted.

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B.2 Greenhouse Effect

Understandings

- The conservation of energy.
- Emissivity as the ratio of the power radiated per unit area by a surface compared to that of an ideal black surface at the same temperature as given by $\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4}$.
- Albedo as a measure of the average energy reflected off a macroscopic system as given by $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$.
- The Earth's albedo varies daily and is dependent on cloud formations and latitude.
- The solar constant *S*.
- The incoming radiative power is dependent on the projected surface of a planet along the direction of the path of the rays, resulting in a mean value of the incoming intensity being $\frac{S}{4}$.
- Methane CH_4, water vapor H_2O, carbon dioxide CO_2, and nitrous oxide N_2O are the main greenhouse gases and each of these has origins that are both natural and created by human activity.
- The absorption of infrared radiation by the main greenhouse gases in terms of the molecular energy levels.
- The augmentation of the greenhouse effect due to human activities is known as the enhanced greenhouse effect.

Equations

$$\text{emissivity} = \frac{\text{power radiated per unit area}}{\sigma T^4}$$

$$\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$$

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: State the law of conservation of energy.

2. C: State the definition, equation, and units for *emissivity*. What is the *emissivity* of a really dark colored object? What is the *emissivity* of a really light colored object?

3. C: State the definition, equation, and units for *albedo*. What is the *albedo* of a really dark colored object? What is the *albedo* of a really light colored object?

4. C: What is the mathematical relationship between the *albedo* and *emissivity* of an object?

5. E: A naked person has a surface area of $1.80\ \mathrm{m}^2$, an emissivity of 0.980, and a skin temperature of 37.0°C. This naked person is in a room with room temperature of 20.0°C. How much energy does this person lose per minute?

6. E: By which factor does the power emitted by an object decrease when its temperature decreases from 800.0 K to 500.0 K?

7. E: On a hot summer day a forest receives an intensity of approximately $1{,}210\ \frac{\mathrm{W}}{\mathrm{m}^2}$. If the forest has an albedo of approximately 0.122 then determine how much energy is absorbed and reflected every second by each square meter.

8. E: The planet Saturn has an average surface temperature of -178°C and a radius of approximately 5.82×10^7 m. Suppose Saturn has an emissivity of approximately 0.650. Determine the rate of thermal energy emitted.

9. C: What is the meaning of the Sun-Earth *solar constant*?

10. E: The luminosity of the Sun is approximately 3.828×10^{26} W. The average distance from the Sun to Earth is 1.5×10^{11} m. Use the equation $I = \frac{P}{A} = \frac{P}{4\pi d^2}$ to determine the Sun-Earth *solar constant*.

11. C: Describe the equation $\bar{I} = \frac{P}{A} = \frac{S}{4}$.

12.E: The average albedo of Earth is approximately 0.300 and the average emissivity of the Earth is approximately 0.600. Use the solar constant to determine the average temperature of the Earth.

13.E: The average albedo of Earth is approximately 0.300. Use the solar constant to determine the average intensity reaching the Earth during the day or night.

14.C: Define the *greenhouse effect* and the *enhanced greenhouse effect*. What are the four major *greenhouse gases*? State their name and chemical formula.

Part 2: Browse these websites for more information on climate change

The world's most viewed site on global warming and climate change
www.wattsupwiththat.com

Climate Depot: Redefining Global Warming Reporting
https://www.climatedepot.com/

Part 3: Explain what went wrong from these climate predictions

https://cei.org/blog/wrong-again-50-years-of-failed-eco-pocalyptic-predictions/

https://extinctionclock.org/

https://mishtalk.com/economics/lets-review-50-years-of-dire-climate-forecasts-and-what-actually-happened/

1. 1967 Salt Lake Tribune: Dire Famine Forecast by 1975, Already Too Late
2. 1969 NYT: "*Unless we are extremely lucky, everyone will disappear in a cloud of blue steam in 20 years. The situation will get worse unless we change our behavior.*"
3. 1970 Boston Globe: Scientist Predicts New Ice Age by 21st Century said James P. Lodge, a scientist at the National Center for Atmospheric Research.
4. 1971 Washington Post: Disastrous New Ice Age Coming says S.I. Rasool at NASA.
5. 1972 Brown University Letter to President Nixon: Warning on Global Cooling
6. 1974 The Guardian: Space Satellites Show Ice Age Coming Fast
7. 1974 Time Magazine: Another Ice Age "Telling signs everywhere. Since the 1940s mean global temperatures have dropped 2.7 degrees F."
8. 1974 "Ozone Depletion a Great Peril to Life" University of Michigan Scientist
9. 1976 NYT The Cooling: University of Wisconsin climatologist Stephen Schneider laments about the "deaf ear his warnings received."
10. 1988 Agence France Press: Maldives will be Completely Under Water in 30 Years.
11. 1989 Associated Press: UN Official Says Rising Seas to 'Obliterate Nations' by 2000.
12. 1989 Salon: *New York City's West Side Highway underwater by 2019* said Jim Hansen the scientist who lectured Congress in 1988 about the greenhouse effect.

13. 2000 The Independent: "*Snowfalls are a thing of the past. Our children will not know what snow is*," says senior climate researcher.
14. 2004 The Guardian: The Pentagon Tells Bush Climate Change Will Destroy Us. "Britain will be Siberian in less than 20 years," the Pentagon told Bush.
15. 2008 Associate Press: NASA Scientist says "We're Toast. In 5-10 years the Arctic will be Ice Free"
16. 2008 Al Gore: Al Gore warns of ice-free Arctic by 2013.
17. 2009 The Independent: Prince Charles says Just 96 Months to Save the World. "*The price of capitalism is too high*."
18. 2009 The Independent: Gordon Brown says "*We have fewer than 50 days to save our planet from catastrophe*."
19. 2013 The Guardian: The Arctic will be Ice Free in Two Years. "The release of a 50 gigaton of methane pulse" will destabilize the planet.
20. 2013 The Guardian: US Navy Predicts Ice Free Arctic by 2016. "The US Navy's department of Oceanography uses complex modeling to makes its forecast more accurate than others.
21. 2014 John Kerry: "*We have 500 days to Avoid Climate Chaos*" discussed Sec of State John Kerry and French Foreign Minister Laurent Fabious at a joint meeting.

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B.3 Gas Laws

Understandings

- Pressure is given by $P = \frac{F}{A}$ where F is the force exerted perpendicular to the surface.
- The amount of substance n as given by $n = \frac{N}{N_{\text{A}}}$ where N is the number of molecules and N_A is the Avogadro constant.
- Ideal gases are described in terms of the kinetic energy and constitute a modeled system used to approximate the behavior of real gases.
- The ideal gas law equation can be derived from the empirical gas laws for constant pressure, constant volume, and constant temperature as given by $\frac{PV}{T} = \text{constant}$.
- The equations governing the behavior of ideal gases as given by $PV = nk_{\text{B}}T$ and $PV = nRT$.
- The change in momentum of particles due to collisions with a given surface gives rise to pressure in gases and, from that analysis, pressure is related to the average translational speed of molecules as given by $P = \frac{1}{3}\rho v^2$.
- The relationship between the internal energy U of an ideal monatomic gas and the number of molecules or amount of substance as given by $U = \frac{3}{2}Nk_{\text{B}}T$ or $U = \frac{3}{2}RnT$.
- The temperature, pressure, and density conditions under which an ideal gas is a good approximation of a real gas.

Equations

$P = \frac{F}{A}$

$N = \frac{N}{N_{\mathrm{A}}}$

$\frac{PV}{T} = \text{constant}$

$PV = nRT = Nk_{\mathrm{B}}T$

$P = \frac{1}{3}\rho v^2$

$U = \frac{3}{2}nRT = \frac{3}{2}Nk_{\mathrm{B}}T$

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: Define and give the units for each variable for *pressure* $P = \frac{F}{A}$. Is it a scalar or vector? Do not confuse pressure *P* with power *P* or momentum $\vec{p}$ or density ρ!

2. E: The surface area of an average human male foot is approximately $651\ \mathrm{cm}^2$. Determine the pressure on each foot of a 75.0 kg man standing on both feet.

3. C: Define *Avogadro's constant* N_A.

4. C: Define and give the units for each variable for a *mole* $n = N/N_A$.

5. E: Determine the number of molecules in 3.25 moles of $\mathrm{O_2}$.

6. E: Determine the number of moles of 1.47×10^{26} particles.

7. E: Consider H_2O.
   a. What is the molar mass of H_2O?

   b. How many moles are in 50.0 grams of H_2O?

   c. How many grams are in 18.0 moles of H_2O?

8. E: Consider CO_2.
   a. What is the molar mass of CO_2?

   b. How many moles are in 26.0 grams of CO_2?

   c. How many grams are in 32 moles of CO_2?

9. E: Consider CH_4.
   a. What is the molar mass of CH_4?

   b. How many moles are in 46.0 grams of CH_4?

   c. How many grams are in 146 moles of CH_4?

10. C: Define and give the units of *atomic mass unit u.*

11.C: State some characteristics of an *ideal gas.*

12.C: What are some differences between an *ideal gas* and a *real gas*?

13.C: Define and draw a graph showing *Boyle's Law.*

14.C: Define and draw a graph showing *Charles' Law.*

15.C: Define and draw a graph showing *Gay-Lussac's Law.*

16.C: Take *Boyle's Law*, *Charles' Law*, and *Gay-Lussac's Law* to obtain a general equation for an ideal gas.

17.C: Define and give the units of each variable for the *Ideal Gas Law* $PV = nRT$.

18.C: Define and give the units of each variable for the *Ideal Gas Law* $PV = Nk_{\mathrm{B}}T$.

19.E: What is the number of moles of an ideal gas in 80.0 cm^3 at room temperature of 20.0°C and a pressure of 1.00×10^5 Pa?

20.E: What is the volume of 22.0 moles of an ideal gas when it fills a cylinder at a temperature of 40.0°C and a pressure of 1.01×10^5 Pa?

21.E: What is the temperature of 0.255 moles of an ideal gas when it fills a volume of 225 cm^3 at a pressure of 1.01×10^5 Pa?

22.E: Three moles of an ideal gas originally occupies a volume of $120.\ \text{cm}^3$ with a pressure of 1.01×10^5 Pa at a temperature of $23.0°\text{C}$. What will be its new volume if its pressure is held constant and its temperature increases to $35.0°\text{C}$?

23.E: Five moles of an ideal gas originally occupies a volume of $160.\ \text{cm}^3$ with a pressure of 1.01×10^5 Pa at a temperature of $23.0°\text{C}$. What will be its new pressure if its volume is held constant and its temperature increases to $75.0°\text{C}$?

24.E: Two moles of an ideal gas originally occupies a volume of $346.\ \text{cm}^3$ with a pressure of 1.01×10^5 Pa at a temperature of $30.0°\text{C}$. What will be its new pressure if its volume increases to $362.\ \text{cm}^3$ and its temperature is held constant?

25.C: Define and give the units for each variable for the equation for the kinetic theory of an ideal gas $P = \frac{1}{3}\rho v^2$.

26.E: The density of air on Earth is approximately $1.29\ \frac{\text{kg}}{\text{m}^3}$ at a pressure of 1.01×10^5 Pa. Assume the air is an ideal gas. Determine the average speed of the air.

27.E: The density of air on Mars is approximately $0.200\ \frac{\text{kg}}{\text{m}^3}$ at a pressure of 610 Pa. Assume the air is an ideal gas. Determine the average speed of the air.

28.C: Define and give the units for each variable for the equation for the internal energy of an ideal monatomic gas $U = \frac{3}{2}nRT = \frac{3}{2}Nk_\text{B}T$.

29.E: Determine the internal energy of 7.42 moles of an ideal gas at a temperature of 32.0°C.

30.E: Determine the internal energy of 2.84×10^{24} particles of an ideal gas at a temperature of 27.0°C.

31.E: Use the equation $\overline{E_\text{K}} = \frac{3}{2}k_\text{B}T$ to determine the average kinetic energy and speed of O_2 at a room temperature of 20.0°C. Assume O_2 is an ideal gas.

32.E: Use the equation $\overline{E_\mathrm{K}} = \frac{3}{2}k_\mathrm{B}T$ to determine the average kinetic energy and speed of $\mathrm{CO_2}$ at a temperature of 23.0°C. Assume $\mathrm{CO_2}$ is an ideal gas.

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B.4 Thermodynamics

Additional HL Understandings

- The first law of thermodynamics, as given by $Q = \Delta U + W$, results from the application of conservation of energy to a closed system and relates the internal energy of a system to the transfer of energy as heat and as work.
- The work done by or on a closed system as given by $W = P\Delta V$ when its boundaries are changed can be described in terms of pressure and changes of volume of the system.
- The change in internal energy, as given by $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_{\mathrm{B}}\Delta T$, of a system is related to the change of its temperature.
- Entropy S is a thermodynamic quantity that relates to the degree of disorder of the particles in a system.
- Entropy can be determined in terms of macroscopic quantities such as thermal energy and temperature as given as $\Delta S = \frac{\Delta Q}{T}$ and also in terms of the properties of individual particles of the system as given by $S = k_{\mathrm{B}} \ln \Omega$ where k_B is the Boltzmann constant and Ω is the number of possible microstates of the system.
- The second law of thermodynamics refers to the change in entropy of an isolated system and sets constraints on possible physical processes and on the overall evolution of the system.
- Processes in real isolated systems are almost always irreversible and consequently the entropy of a real isolated system always increases.
- The entropy of a non-isolated system can decrease locally, but this is compromised by an equal or greater increase of the entropy of the surroundings.
- Isovolumetric, isobaric, isothermal, and adiabatic processes are obtained by keeping one variable fixed.
- Adiabatic processes in monatomic ideal gases can be modeled by the equation as given by $PV^{\frac{5}{3}} = \text{constant}$.
- Cyclic gas processes are used to run heat engines.
- A heat engine can respond to different cycles and is characterized by its efficiency as given by $\eta = \frac{\text{useful work}}{\text{input energy}}$.

- The Carnot cycle sets a limit for the efficiency of a heat engine at the temperatures of its heat reservoirs as given by $\eta_{\text{carnot}} = 1 - \frac{T_{\text{c}}}{T_{\text{h}}}$.

Additional HL Equations

$Q = \Delta U + W$

$W = P\Delta V$

$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_{\text{B}}\Delta T$

$\Delta S = \frac{\Delta Q}{T}$

$S = k_{\text{B}} \ln \Omega$

$PV^{\frac{5}{3}} = \text{constant}$

$\eta = \frac{\text{useful work}}{\text{input energy}}$

$\eta_{\text{carnot}} = 1 - \frac{T_{\text{c}}}{T_{\text{h}}}$

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: Define *thermodynamics.*

2. C: Define a *closed system*.

3. C: Define an *isolated system*.

4. C: State the *first law of thermodynamics.*

5. C: Consider a system filled with an ideal gas and the equation for the law of conservation of energy $Q = \Delta U + W$.

   a. Define ΔU. What is the meaning if $\Delta U > 0$ Joules? $\Delta U = 0$ Joules? $\Delta U < 0$ Joules?

b. Define W. What is the meaning if $W > 0$ Joules? $W = 0$ Joules? $W < 0$ Joules?

c. Define Q. What is the meaning if $Q > 0$ Joules? $Q = 0$ Joules? $Q < 0$ Joules?

6. E: 8.42×10^3 J of heat is given to a closed system while the system does 4.37×10^3 J of work. What is the change in internal energy of the system during this process?

7. E: A closed system absorbs 2.33×10^3 J and at the same time 1.24×10^3 J of work is done on it. What is the change in internal energy of the system during this process?

8. E: 9.97×10^3 J is removed from a gas held at a constant volume. What is the change in internal energy of the system during this process?

9. E: 246 J of thermal energy is used to compress a gas while its internal energy increases by 122 J. Determine the amount of energy leaving the system.

10. E: In a slow isothermal compression 3.45×10^4 J of work is done on an ideal gas. Determine the work done on the gas.

11. E: During a slow isothermal expansion 3.45×10^4 J of work is done by an ideal gas. Determine the work done by the gas.

12. C: Describe the equation $W = P\Delta V$.

13.E: An ideal gas in a piston is compressed from an initial volume of 1.87×10^{-1} m^3 to a final volume of 1.03×10^{-1} m^3 at a constant pressure of 4.04×10^5 Pa. The initial temperature of the ideal gas, before expansion, is 406 K. Determine the work done on the ideal gas and the final temperature of the ideal gas.

14.E: An ideal gas in a piston is expanded from an initial volume of 9.87×10^{-1} m^3 to a final volume of 1.23×10^{0} m^3 at a constant pressure of 3.03×10^5 Pa. The initial temperature of the ideal gas, before expansion, is 398 K. Determine the work done by the ideal gas and the final temperature of the ideal gas.

15.C: Describe the equation $\Delta U = \frac{3}{2} N k_{\mathrm{B}} \Delta T = \frac{3}{2} nR\Delta T$.

16.C: Define *thermal equilibrium.*

17.C: State the *zeroth law of thermodynamics.*

18.C: What does the area under a *pressure-volume curve* tell us?

a. Define *isothermal process.* Draw three *isothermal processes (isotherms)* on a *pressure vs. volume* graph.

b. Define *isobaric process*. Draw an *isobaric process* on a *pressure vs. volume graph*.

c. Define *isochoric/isovolumetric process*. Draw an *isochoric/isovolumetric* process on a *pressure vs. volume* diagram.

d. Define *adiabatic process*. Draw an *adiabatic process* on a *pressure vs. volume* graph.

19.E: A gas does 1.00×10^3 J of work while a closed system expands adiabatically. Determine the change in internal energy.

20.E: 1.23×10^3 J of work is done on a closed system during an adiabatic compression. Determine the change in internal energy.

21.C: Define *entropy* S. Units?

22.C: Describe the equation $\Delta S = \frac{\Delta Q}{T}$.

23.C: The change in entropy S of a system is defined as $\Delta S = \frac{\Delta Q}{T}$.

a. What can we do to make ΔS positive?

b. What can we do to make ΔS negative?

24.E: A cup of hot chocolate at a temperature of 90.0°C is in a room with an ambient temperature of 23.0°C. If the temperature of the hot chocolate and room do not change and 1.97×10^3 J of energy flows out of the hot chocolate to the room then determine the change in entropy.

25.E: Two large cubes filled with water are separated by a thin thermally conducting metal plate. The temperature of the water in cube 1 is 82.0°C and the temperature of the water in cube 2 is 39.0°C. Determine the change in entropy of the whole system if heat flows between the plate at 249 Joules per second.

26.E: 400. g of ice at 0.00°C melts to water at a constant temperature. The latent heat of fusion of H_2O is $3.34 \times 10^5 \ \frac{\text{J}}{\text{kg}}$. Determine the change in entropy.

27.E: 500. g of water at 0.00°C freezes to ice at a constant temperature. The latent heat of fusion of $\mathrm{H_2O}$ is $3.34 \times 10^5\ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

28.E: 600. g of boiling water at 100.°C vaporizes to steam at a constant temperature. The latent heat of vaporization of $\mathrm{H_2O}$ is $2.26 \times 10^6\ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

29.E: 800. g of steam at 100.°C condenses to water at a constant temperature. The latent heat of vaporization of $\mathrm{H_2O}$ is $2.26 \times 10^6\ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

30.E: A piston is slowly compressed so the temperature of the ideal gas inside it remains at 40.0°C. 748 J of work is done on the gas. Determine the change in entropy of the gas.

31.E: A piston is slowly expanded so the temperature of the ideal gas inside it remains at 68.3°C. 498 J of work is done by the gas. Determine the change in entropy of the gas.

32.C: Describe the equation $S = k_{\mathrm{B}} \ln \Omega$.

33.E: Determine the entropy of a system which has 7.53×10^{45} microstates.

34.C: State the *second law of thermodynamics.*

35.C: State the *Clausius version* of the *second law of thermodynamics.*

36.C: State the *Kelvin version* of the *second law of thermodynamics.*

37.C: State the *arrow of time* and *entropy* in terms of the *second law of thermodynamics*.

38.C: State the *third law of thermodynamics.*

39.C: Describe the equation $PV^{\frac{5}{3}} = \text{constant}$.

40.E: An ideal gas is initially held at a pressure of 1.23×10^4 Pa, a volume of 9.06×10^{-1} m^3, and a temperature of 348 K. The ideal gas then expands adiabatically to a new volume of 1.00×10^1 m^3. Determine the final pressure and final temperature of the ideal gas.

41.E: An ideal gas is initially held at a pressure of 7.65×10^4 Pa, a volume of 9.63×10^{-1} m^3, and a temperature of 388 K. The ideal gas then compresses adiabatically to a new volume of 8.28×10^{-1} m^3. Determine the final pressure and final temperature of the ideal gas.

42.E: In an adiabatic process the volume of a piston increases from $145\ \text{cm}^3$ to $194\ \text{cm}^3$. By which factor does the pressure change?

43.E: In an adiabatic process the pressure of a piston increases from 3.03×10^5 Pa to 7.07×10^5 Pa. By which factor does the volume change?

44.C: Define *heat engine* and *heat pump.*

45.C: **Use a pencil!** Carefully and clearly draw the *Carnot cycle*. Label the vertical axis and the horizontal axis. Label the adiabatic processes and isothermal processes.

46.C: In general the efficiency of an engine is $\eta = \frac{\text{useful work}}{\text{input energy}}$. For a *Carnot engine* $\eta_{\text{carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$.

a. Is the *Carnot cycle* a fast or slow process?

b. Is the *Carnot cycle* realistic?

.

c. Is the *Carnot cycle* efficient?

47.E: Calculate the efficiency of a Carnot engine operating between the following temperatures.

a. 123°C and 23.0°C

b. 223°C and 123°C

c. 323°C and 223°C

48.E: Suppose you have 12 two-sided fair unbiased coins. You throw them all up and count the number of heads and number of tails. You want to determine the number of arrangements to land one head, two heads, three heads, etc. and also its probability. Complete the table below:

Number of Heads	Number of Arrangements	Probability
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Name: ______________________

Class: ______________________

Due Date: ______________________

B.5 Current and Circuits

Understandings

- Cells provide a source of emf.
- Chemical cells and solar cells as the energy source in circuits.
- Circuit diagrams represent the arrangement of components in a circuit.
- Direct current (dc) I as a flow of charge carriers as given by $I = \frac{\Delta q}{\Delta t}$.
- The electric potential difference V is the work done per unit charge on moving a positive charge between two points along the path of the current as given by $V = \frac{W}{q}$.
- The properties of electrical conductors and insulators in terms of mobility or charge carriers.
- Electric resistance and its origin.
- Electrical resistance R as given by $R = \frac{V}{I}$.
- Resistance as given by $\rho = \frac{RA}{L}$.
- Ohm's law.
- The ohmic and non-ohmic behavior of electrical conductors, including the heating effect of resistors.
- Electrical power P dissipated by a resistor as given by $P = IV = I^2R = \frac{V^2}{R}$.
- The combinations of resistors in series and parallel circuits.

Series circuits	Parallel circuits
$I = I_1 = I_2 = \cdots$	$I = I_1 + I_2 + \cdots$
$V = V_1 + V_2 + \cdots$	$V = V_1 = V_2 = \cdots$
$R_s = R_1 + R_2 + \cdots$	$\frac{1}{R_\text{p}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

- Electric cells are characterized by their emf ε and internal resistance r as given by $\varepsilon = I(R + r)$.

- Resistors can have variable resistance.

Equations

$I = \frac{\Delta q}{\Delta t}$

$V = \frac{W}{q}$

$R = \frac{V}{I}$

$\rho = \frac{RA}{L}$

$P = IV = I^2R = \frac{V^2}{R}$

Series circuits	Parallel circuits
$I = I_1 = I_2 = \cdots$ $V = V_1 + V_2 + \cdots$ $R_s = R_1 + R_2 + \cdots$	$I = I_1 + I_2 + \cdots$ $V = V_1 = V_2 = \cdots$ $\frac{1}{R_s} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

$\varepsilon = I(R + r)$

If you are interested in learning more about electricity and magnetism then please read the book *Electricity and Magnetism* by Edward M. Purcell and David J. Morin.

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: Define *electric potential difference*. Units?

2. C: What are the units of *voltage*?

3. C: **Use a pencil and ruler!** The work done in moving a charge is given by the equation $W = q \times \Delta V$. Draw and label a diagram to describe this equation.

4. C: What is *charge q*? Units?

5. C: Define *electric current I* and state its equation and units. Do not confuse *current I* with *impulse* $\vec{J}$!

6. C: What is the relationship in magnitude and direction between *electron flow* and *current* in a conductor?

7. C: Define resistance. Give the units of *resistance* Ω.

8. C: What is the resistance of an ideal wire?

9. C: Define *resistor*. Do resistors increase or decrease the current in a circuit? Why is it necessary to have a resistor in a circuit?

10. C: Define *resistivity* ρ. Do not confuse resistivity ρ with density ρ!

11. C: What is the *resistance* of a non-ideal wire directly proportional to?

12. C: What is the resistance of a non-ideal wire inversely proportional to?

13. E: A piece of wire 40.0 cm long is measured to have a resistance of 7.20 Ω. What will be the resistance of an otherwise identical wire which has a length of 120. cm?

14.E: A piece of wire, which has a diameter of 0.500 mm, is measured to have a resistance of 8.40 Ω. What will be the resistance of an otherwise identical wire which has a diameter of 0.250 mm?

15.C: Define *Ohm's Law*. Draw a current vs. voltage graph of a resistor obeying Ohm's law.

16.C: What does a *thermistor* do? Draw a *resistance vs. temperature* graph of a thermistor.

17.C: What does a *light-dependent resistor* (LDR) do?

18.C: What does a *potentiometer* do?

19.C: Define *non-ohmic*.

20.C: Give three versions of the equation for *electrical power.*

21.E: A current of 0.870 Amperes flows through a certain light bulb when it is attached to a 115. Volt power supply. How much power does this light bulb dissipate?

22.E: A 25.0 Ω resistor is connected to a 5.70 Volt battery with negligible internal resistance.

a. What will be the current flowing through the resistor?

b. How much power will be dissipated in this resistor?

23.E: A certain light bulb is designed to dissipate 5.00 W of power when attached to a 12.0 V source. What is the resistance of the light bulb filament?

24.E: A 25.0 Ω resistor and a 75.0 Ω resistor are connected in series across a 12.0 V source. How much power will be consumed by the 25.0 Ω resistor?

25.E: A 55.0 Ω resistor is attached to a 12.0 V power supply. This resistor is then immersed in a Styrofoam cup containing 25.0 g of water initially at a temperature of 22.5°C for a period of 150. s.

a. How much power is being delivered to the resistor?

b. How much energy will be delivered to the water during these 150. s?

c. What will be the final temperature of the water?

26.C: Define *electromotive force emf*. What are its units?

27.C: State *Kirchhoff's loop rule*. Which conservation rule does this law obey?

28.State *Kirchhoff's junction rule*. Which conservation rule does this law obey?

29.C: Resistors in series have the same ___________.

30.C: Resistors in parallel have the same ___________.

31.C: How can we simplify many *resistors in series*?

32.C: How can we simplify many *resistors in parallel*?

33.C: What does an *ammeter* do? Draw its symbol. What is a characteristic of an *ideal ammeter*? How/Where do we insert an *ammeter* in a circuit?

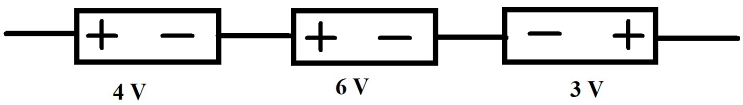
34.C: What does a *voltmeter* do? Draw its symbol. What is a characteristic of an *ideal voltmeter*? How/Where do we insert a *voltmeter* in a circuit?

35.E: Six 2.02 Volt cells are connected in series. What will be the total emf produced?

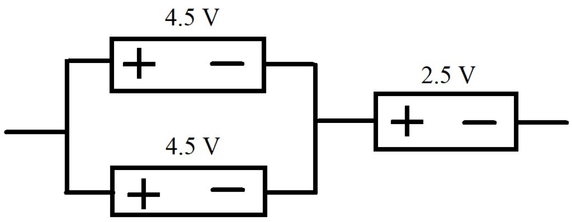
36.E: What will be the emf produced by four 1.50 Volt cells connected in series?

37.E: What will be the emf produced by three 6.00 Volt batteries connected in parallel?

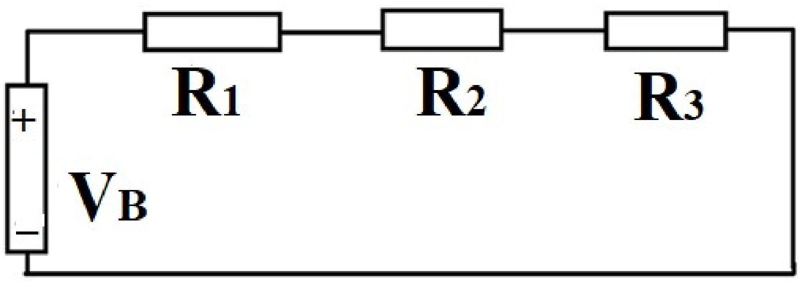
38.E: What will be the emf produced by the combination of cells below?



39.E: What will be the emf produced by the combination of cells below?



40.E: Solve for the unknowns. Give your answers in reduced fractions.



Given:

$V_B = 10\text{ V}$

$R_1 = 2\Omega$

$R_2 = 4\Omega$

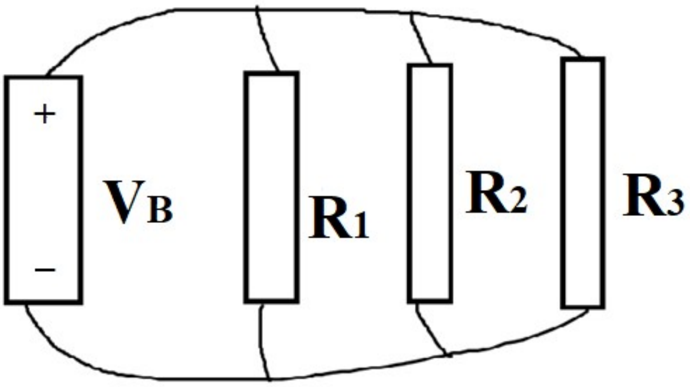
$R_3 = 6\Omega$

$R_{\text{equivalent}} =$ $I_{\text{battery}} =$	$V_1 =$ $V_2 =$ $V_3 =$	$I_1 =$ $I_2 =$ $I_3 =$

What will happen to the current leaving the battery if the number of resistors in series increases? Will the current increase, decrease, or stay the same?

What will happen to the overall resistance of the circuit if the number of resistors in series increases? Will the overall resistance increase, decrease, or stay the same?

41.E: Solve for the unknowns. Give your answers in reduced fractions.

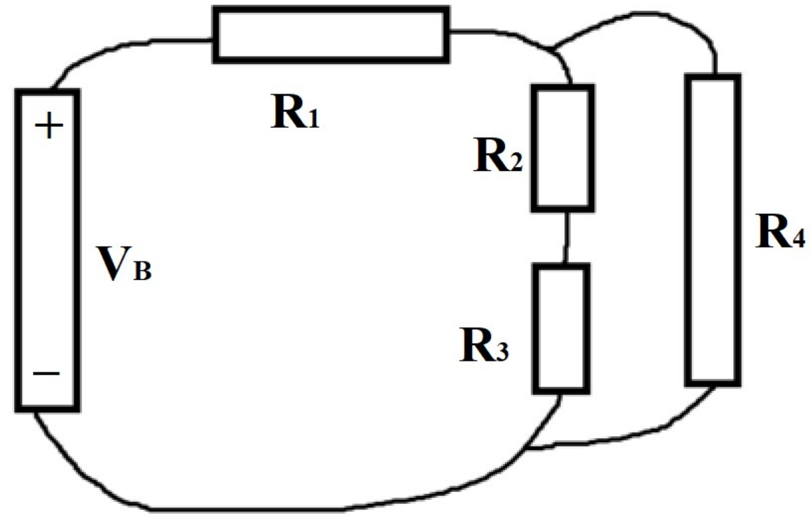
	Given: $V_B = 10$ V $R_1 = 2\ \Omega$ $R_2 = 4\ \Omega$ $R_3 = 6\ \Omega$

$R_{\text{equivalent}} =$ $I_{\text{battery}} =$	$V_1 =$ $V_2 =$ $V_3 =$	$I_1 =$ $I_2 =$ $I_3 =$

What will happen to the current leaving the battery if the number of resistors in parallel increases? Will the current increase, decrease, or stay the same?

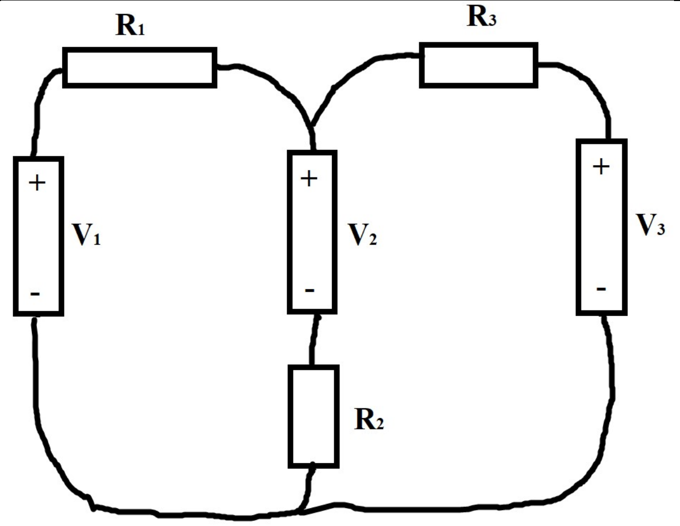
What will happen to the overall resistance of the circuit if the number of resistors in parallel increases? Will the overall resistance increase, decrease, or stay the same?

42.E: Solve for the unknowns. Give your answers in reduced fractions.

	Given: $V_B = 10\ \text{V}$ $R_1 = 2\ \Omega$ $R_2 = 4\ \Omega$ $R_3 = 6\ \Omega$ $R_4 = 8\ \Omega$

	$V_1 =$	$I_1 =$
$R_{\text{equivalent}} =$	$V_2 =$	$I_2 =$
$I_{\text{battery}} =$	$V_3 =$	$I_3 =$
	$V_4 =$	$I_4 =$

43.E: Solve for the unknowns. Give your answers in reduced fractions.



$V_1 = 6\ \text{V}$

$V_2 = 11\ \text{V}$

$V_3 = 17\ \text{V}$

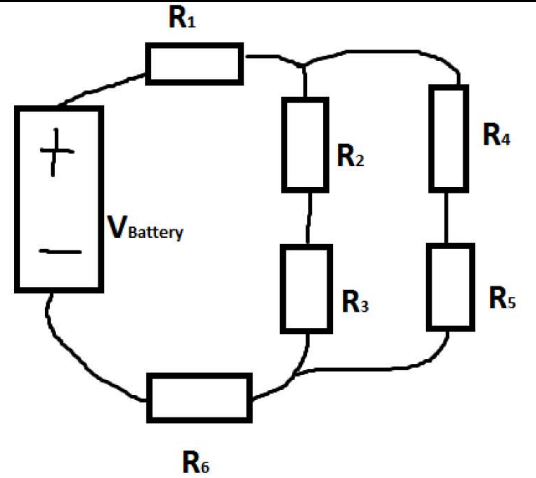
$R_1 = 3\ \Omega$

$R_2 = 1\ \Omega$

$R_3 = 4\ \Omega$

$I_1 =$	$V_1 =$
$I_2 =$	$V_2 =$
$I_3 =$	$V_3 =$

44.E: Solve for the unknowns. Give your answers in reduced fractions.



$V_{\text{battery}} = 10\ \text{V}$

$R_1 = 1\ \Omega$

$R_2 = 2\ \Omega$

$R_3 = 3\ \Omega$

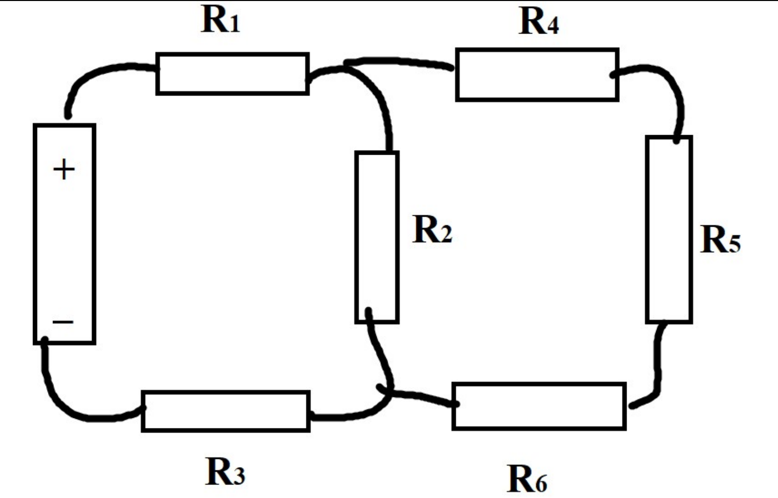
$R_4 = 4\ \Omega$

$R_5 = 5\ \Omega$

$R_6 = 6\ \Omega$

$R_{\text{equivalent}} =$			$I_{\text{battery}} =$		
$I_1 =$	$I_2 =$	$I_3 =$	$I_4 =$	$I_5 =$	$I_6 =$
$V_1 =$	$V_2 =$	$V_3 =$	$V_4 =$	$V_5 =$	$V_6 =$

45.E: Solve for the unknowns. Give your answers in reduced fractions.



$V_{\text{battery}} = 30\text{ V}$

$R_1 = 1\ \Omega$

$R_2 = 2\ \Omega$

$R_3 = 3\ \Omega$

$R_4 = 4\ \Omega$

$R_5 = 5\ \Omega$

$R_6 = 6\ \Omega$

$R_{\text{equivalent}} =$			$I_{\text{battery}} =$		
$I_1 =$	$I_2 =$	$I_3 =$	$I_4 =$	$I_5 =$	$I_6 =$
$V_1 =$	$V_2 =$	$V_3 =$	$V_4 =$	$V_5 =$	$V_6 =$

46.C: What is a *potential/voltage divider*?

47.C: Define *internal resistance r*. Units?

48.C: Define the following variables for the equation $\varepsilon = I(R + r)$. Draw an image to describe this equation.

49.E: A dry cell has an emf of 3.04 V. Its terminal potential drops to zero when a current of 50.0 A passes through it. What is its internal resistance?

50.E: A cell has an emf of 145 V. This means that its terminal voltage is 145 V when no current flows through it. When the terminal potential is 120. V the current through the circuit is 25.0 A.

a. What is the internal resistance of the cell?

b. What will be the terminal potential when the current is 12.0 A?

51.E: A cell with internal resistance is connected to a 3.00 Ω resistor. Determine the internal resistance r of the cell if the current going through it is 2.00 Amps when its ε is 12.0 V.

52.E: A battery with internal resistance is connected to a variable resistor. When the resistor has a resistance R of 12.0 Ω the current is 2.00 Amps. When the resistor has a resistance R of 6.00 Ω the current is 3.00 Amps. Determine the emf ε and internal resistance r of the battery.

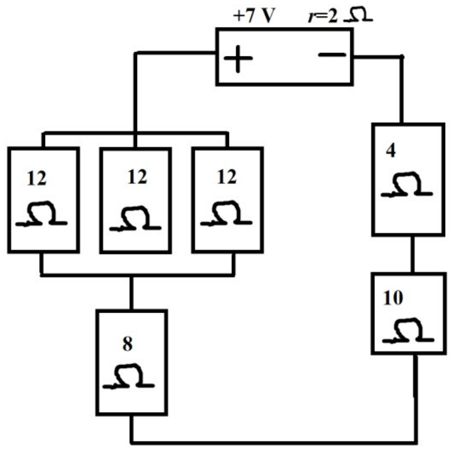
53.E: While attached to a 2.00 Ω resistance the terminal voltage of a battery is measured to be 5.20 V. The open circuit voltage of this same battery is measured to be 6.70 V.

a. What is the internal resistance of the battery?

b. What will be the maximum current that can be delivered by the battery?

54.E: A battery is known to have an emf of 4.60 Volts and an internal resistance of 2.20 Ω. What will be the terminal voltage of this battery while connected to a load of 7.80 Ω?

55.E: Consider the circuit below:



a. What is the total resistance of this circuit?

b. What will be the total current flowing through this circuit?

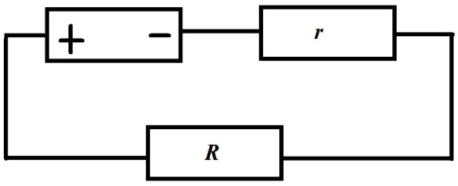
c. What will be the current flowing through each 12.0 Ω resistor?

d. What will be the voltage drop across each of the 12.0 Ω resistors?

e. What will be the terminal voltage of the battery?

f. What will be the voltage drop across the 10.0 Ω resistor?

56.E: A battery, which has an emf of 6.00 V and an internal resistance $r = 0.500\ \Omega$, is connected to a load which has a resistance of $R = 3.50\ \Omega$.



a. What will be the current flowing in this circuit?

b. What will be the voltage drop across the load?

c. How much power is being supplied by the battery?

d. How much power is being consumed by the load?

e. How much power is being consumed by the internal resistance of the battery?

f. With what efficiency is power being delivered to the load in this circuit?