5C-F21 Final B

CLAIRE HATHAWAY

TOTAL POINTS

50.5 / 56

QUESTION 1

20 pts

1.1 0 / 1

- 0 pts Correct. b
- ✓ - 1 pts wrong

1.2 1 / 1

- ✓ - 0 pts Correct b
- 1 pts wrong

1.3 1 / 1

- ✓ - 0 pts Correct. a
- 1 pts wrong

1.4 1 / 1

- ✓ - 0 pts Correct. d
- 1 pts wrong

1.5 1 / 1

- ✓ - 0 pts Correct. a
- 0 pts wrong

1.6 1 / 1

- ✓ - 0 pts Correct. b
- 0 pts wrong

1.7 1 / 1

- ✓ - 0 pts Correct. c
- 1 pts wrong

1.8 1 / 1

- ✓ - 0 pts Correct b
- 1 pts wrong

1.9 0 / 1

- 0 pts Correct. b
- ✓ - 1 pts wrong

1.10 1 / 1

- ✓ - 0 pts Correct. c
- 1 pts wrong

1.11 1 / 1

- ✓ - 0 pts Correct b
- 0 pts wrong

1.12 1 / 1

- ✓ - 0 pts Correct. a
- 1 pts wrong

1.13 0 / 1

- 0 pts Correct. b
- ✓ - 1 pts wrong

1.14 1 / 1

- ✓ - 0 pts Correct
- 1 pts wrong

1.15 1 / 1

- ✓ - 0 pts Correct. b
- 1 pts wrong

1.16 1 / 1

- ✓ - 0 pts Correct. b
- 1 pts wrong

1.17 1 / 1

- ✓ - 0 pts Correct. d
- 1 pts wrong

1.18 1 / 1

✓ - **0 pts** Correct. d

- **1 pts** wrong

1.19 0 / 1

- **0 pts** Correct. d

✓ - **1 pts** wrong

1.20 1 / 1

✓ - **0 pts** Correct. a

- **1 pts** wrong

QUESTION 2

12 pts

2.1 3.5 / 4

- **0 pts** Correct
- **4 pts** no answer
- **0 pts** did not specify how to determine it from these numbers
- **1 pts** did not identify the two numbers that must be compared or identified the wrong numbers

✓ - **0.5 pts** you cannot compare an area with a distance

- **0.5 pts** not length but radius
- **1 pts** wrong conclusion

2.2 4 / 4

✓ - **0 pts** Correct

- **0.5 pts** wrong d (or other numerical error)
- **0.5 pts** Wrong area
- **0.5 pts** wrong formula for C
- **1 pts** No area calculated

2.3 4 / 4

✓ - **0 pts** Correct

- **1 pts** wrong V
- **1 pts** wrong approach, wrong or no Q
- **1 pts** wrong or no formula for UC
- **1 pts** no calculations
- **4 pts** no answer

QUESTION 3

12 pts

3.1 6 / 6

✓ - **0 pts** Correct

- **2 pts** crossed out $$R_3$$ or otherwise dealt with the capacitor incorrectly
- **1 pts** applied power formula using the wrong voltage or current
- **0.5 pts** Remembered the power formula wrong or plugged in numbers into calculator wrong
- **1 pts** Small mistake reducing the resistors
- **2 pts** Multiple mistakes reducing the resistors or otherwise finding the current and voltage splits
- **3 pts** Did not reduce resistors or otherwise ignored voltage and current splits
- **0.5 pts** forgot to combine the batteries

3.2 6 / 6

✓ - **0 pts** Correct

- **0 pts** Correct with mistakes carried over from part (a)
- **4 pts** Only wrote the generic formulas or given values
- **1 pts** small mistake finding voltage across capacitor
- **2 pts** Significant mistake finding the voltage to calculate Q
- **3 pts** Treated the capacitor as if it were in parallel with the 24V or 48V battery
- **3 pts** reduced the circuit as if the capacitor were acting like a wire
- **0.5 pts** Everything correct but forgot formula for charge or plugged in numbers wrong

QUESTION 4

12 pts

4.1 3 / 3

✓ - **0 pts** Correct!

- **1 pts** Incorrect if: plot does not start at $$N_0$$ at $$t = 0$$.
- **1 pts** Incorrect if: the curve does not go as $$e^{-

\lambda t}$$ (anything other than exponential decay).

- **1 pts** Incorrect if: the labelled $$T_{1/2}$$ does not correspond with $$\frac{N_0}{2}$$, or one of the labels is missing.

4.2 2 / 3

- **0 pts** Correct

✓ **- 1 pts Incorrect if: $$^{14} _7 X$$ (or $$^{14} _7 N$$) was not included in the products, or its atomic numbers are labelled incorrectly. Recall that the $$Z$$ in $$^A _Z X$$ is the proton number, so the starting element should be $$^{14} _6 C$$ (additional points weren't taken off for getting the starting element wrong; only based off of how the end product is labelled).**

- **1 pts** Incorrect if: $$e^-$$ (electron) was not included in the products

- **1 pts** Incorrect if: $$\bar{\nu_e}$$ (antineutrino) was not included in the products

4.3 6 / 6

✓ **- 0 pts Correct**

- **2 pts** Incorrect if: There was no attempt to find $$\lambda$$ using $$T_{1/2} = \frac{ln(2)}{\lambda}$$

- **1 pts** Incorrect if: The above method was attempted but did not find $$\lambda \approx 0.00012 yr^{-1}$$

- **2 pts** Incorrect if: $$t$$ wasn't found by using the relation $$\frac{C_{14}}{C_{12}} \cdot 10^{12} = e^{-\lambda t}$$. This relation could be found in several ways. One could've written that formula straight from the lecture slides, plugged in $$\frac{C_{14}}{C_{12}} = 10^{-15}$$, and rearranged to solve for $$t$$. Another way to do this is to use the given ratios to attain some form of $$\frac{N}{N_0} = e^{-\lambda t}$$. This can be done by first recognizing $$N_{C_{12,0}} = N_{C_{12}}$$. Using this, we can write out $$(\frac{C_{12,0}}{C_{14,0}}) \cdot (\frac{C_{14}}{C_{12}}) = \frac{C_{14}}{C_{14,0}}$$, which we can equate to $$e^{-\lambda t}$$. Plugging in the given ratios, we find that $$ \frac{C_{14}}{C_{14,0}} = 10^{12} \cdot 10^{-15} = 10^{-3}$$. Finally, we have $$\frac{C_{14}}{C_{14,0}} = 10^{-3} = e^{-\lambda t}$$, and can solve for $$t$$ from there.

- **1 pts** Incorrect if: $$\frac{C_{14}}{C_{12}} \cdot 10^{12} = e^{-\lambda t}$$ was used, but plugged in $$10^{15}$$ instead of $$10^{-15}$$. Note that the given ratio was $$\frac{C_{12}}{C_{14}} = 10^{15}$$, and not $$\frac{C_{14}}{C_{12}}$$. One would get a negative time if this mistake was made.

- **1 pts** Incorrect if: The final solution is not approximately $$5.7 *10^4$$ years

Problem 1

(20 points)

(each multiple-choice question has only one correct answer)

→ U

1. You move an electron closer to a negative charge its potential energy will ...

(a) stay the same.

(b) increase.

(c) decrease.

U always decreases

2. You place a neutral water molecule next to a large positive point charge +Q. Which of the following is true?

(a) The water molecule will not experience any net electric force.

(b) The water molecule will be attracted by the point charge.

(c) The water molecule will be repelled by the point charge.

water form dipole

but maybe no force?

3. You place a conducting metal sphere with no net charge next to a negative point charge. The conducting sphere will ...

(a) be attracted by the negative point charge.

(b) be repelled by the negative point charge.

(c) not experience any electric force due to due the point charge.

form dipole

4. A hollow positively charged metal sphere of radius R=6 cm has an electric potential of +10 kV at its surface. What is the electric potential inside the sphere at R=3 cm?

(a) 0

(b) 2.5 kV

(c) 5 kV

(d) 10 kV

constant inside sphere

5. You connect three capacitors with capacitance C, 2C, 3C in parallel to a battery. Which capacitor will have the largest potential difference between the plates?

(a) all the same

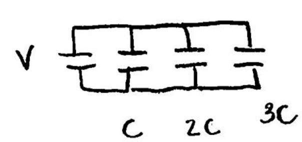
(b) C

(c) 2C

(d) 3C

↓ V

all same b/c parallel?



V constant

6. A parallel plate capacitor is charged with a battery and stays connected to the battery. If you fill the space between the plates with water (K=80) the charge on the plates ...

(a) decreases.

(b) increases.

(c) stays the same.

$\uparrow C = K \varepsilon_0 \frac{A}{d}$ $\qquad \uparrow C = \frac{Q \uparrow}{V}$

7. For capacitors that are connected in series, what property is the same for each of the capacitors?

(a) stored energy. U

(b) electric field. E

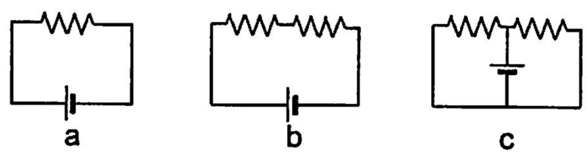
(c) charge on the plates. Q

(d) potential across each capacitor. V

constant I & Q

✗ 8. Consider the three circuits shown below with identical bulbs and batteries. Which circuit produces the least light?

lowest P



– share current

10 V 10 Ω

a: 10 b: 5 c: 20

$I = \frac{V}{R}$ $\quad P = I \cdot V$

$\uparrow P = I^2 R \uparrow$ $\quad \downarrow P = \frac{V^2}{R \uparrow}$ $\quad P = I \cdot V \downarrow \uparrow$

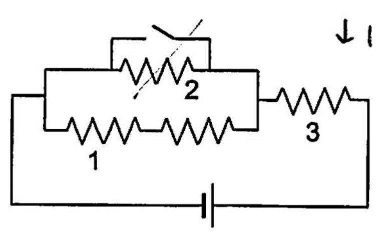
(a) Circuit a

(b) Circuit b

(c) Circuit c

(d) All three circuits produce exactly the same light.

9. Consider the circuit shown with four identical bulbs. What happens to the brightness of the bulbs when you close the switch?



$\downarrow I = \frac{V}{R \uparrow}$ close → 1, w, 3 in series

Req ↑ so I ↓

3 def ↓

(a) bulb 1 gets dimmer and bulb 3 stays the same.

(b) bulb 1 goes out and bulb 3 gets brighter

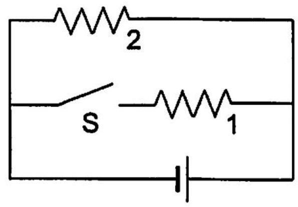
(c) bulb 1, 2 and 3 all get dimmer.

(d) bulb 1 gets brighter and bulb 3 gets brighter.

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

1 sees less V so less I so less P

10. What happens to the brightness of the bulbs when you close the switch?



2 same b/c still seeing same V

1 turns on

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

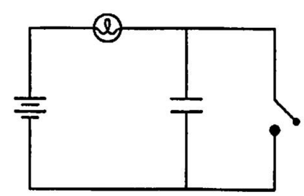
(a) bulb 1 turns on and bulb 2 turns off.

(b) bulb 1 turns on and bulb 2 dims.

(c) bulb 1 turns on and bulb 2 stays the same.

(d) both bulbs get brighter.

11. In the circuit below, the switch is initially closed and the bulb glows brightly. What happens to the brightness of the bulb when the switch is opened?



gradually dims b/c goes to capacitor

(a) The brightness will not change.

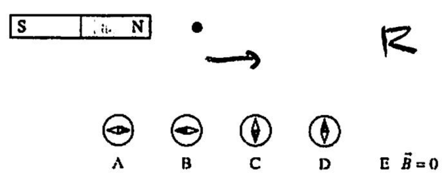
(b) The bulb gradually dims.

(c) The bulb initially brightens and then gradually dims.

(d) The bulb gradually brightens.

12. A compass is place on the black dot next to a bar magnet. In which direction will the needle point?

L



R

(a) N to the right.

(b) N to the left.

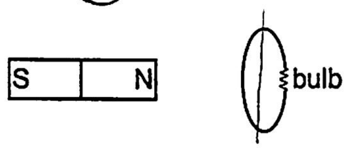
(c) N down.

(d) N up.

(e) The magnetic field is zero.

alligns w/ bar magnet?

13. A tiny light bulb is connected to the ends of a conducting, circular loop of wire as shown in the figure. Which of the following actions will not result in the bulb turning on?



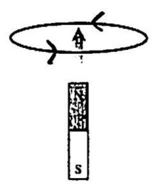
(a) Moving the loop closer to the magnet (to the left).

(b) Rotating the loop around its symmetry axis.

(c) Moving the loop up or down in the figure (perpendicular to the axis of the bar magnet).

(d) Collapsing the loop so that its area decreases.

14. If the north pole of a magnet moves toward the loop from below as shown, in what direction is the induced current (when viewed from the top)?



(a) Counterclockwise.

(b) Clockwise.

(c) There is no induced current

15. What happens to the emission of a blackbody as its temperature decreases?

(a) It gets dimmer and the wavelength decreases.

(b) It gets dimmer and the wavelength increases.

(c) It gets brighter and the wavelength decreases.

(d) It gets brighter and the wavelength increases.

16. When a radioactive nucleus decays by emitting an alpha particle, the atomic mass number of the nucleus ...

(a) increases by 4.

(b) decreases by 4.

(c) increases by 2.

(d) decreases by 2.

17. When a radioactive nucleus decays by emitting a beta particle, the atomic number Z of the nucleus changes by ...

(a) 0.

(b) 4.

(c) 2.

(d) 1.

+/- 1

18. A radioactive isotope has a half life of 2 years. What fraction of the original number of isotopes remains after 6 years?

(a) 1/2

(b) 1/4

(c) 1/6

(d) 1/8

$T_{1/2}$, t, $\frac{N}{N_0}$

$\frac{N}{N_0} = \exp(-\lambda t)$

$\lambda = \frac{\ln(2)}{T_{1/2}} = 0.347$

$\frac{N}{N_0} = \exp(-0.347 \cdot 6) = 0.125$

✗ 19. Atomic nuclei that are all isotopes of an element all have the same...

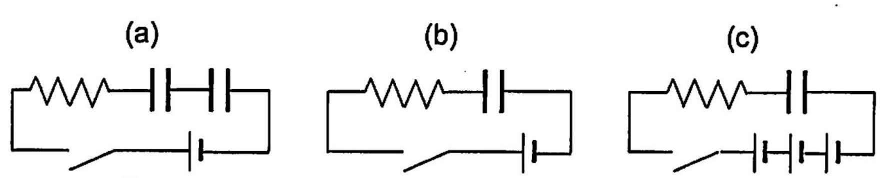
(a) number of neutrons.

(b) number of nucleons.

(c) mass.

(d) number of protons.

20. The batteries, resistors and capacitors in the three figures below are all identical. Which circuit charges the capacitors the fastest (from zero charge) when you close the switch?



↑ will have smallest C_{eq}

(a) a

(b) b

(c) c

C & V change

$C = \frac{Q}{V} \rightarrow Q = C \cdot V$

Smallest C & V combo will charge fastest?

in series, smallest C charges faster

$C_{series} = \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} \ldots$

(extra space)

(extra space)

K = 15

r = 2 × 10⁻⁶ m

membrane = 5 × 10⁻⁹ m L = 0.02 m

Problem 2

(12 points)

A nerve cell in your brain could be modeled as a long thin cylinder with a radius of 2 μm and a length of 2 cm. It is surrounded by a 5 nm thick insulating membrane which has a dielectric constant of K=15.

(a) Could we reasonably model the membrane of this cell as a parallel plate capacitor? What two numbers provided here must be compared to determine this? *(4 points)*

– membrane itself is (so d = 5nm

Yes we can. We need to compare plate seperation and area. Plate seperation will be the distance between the membrane (5×10^{-9} m). Area will be it's length x circumfrence (0.02 m $\times$ 1.26×10^{-5} m) = 2.52×10^{-7}

↓

$C = \pi d = \pi(2)(2 \times 10^{-6}) = 1.26 \times 10^{-5}$

(b) What is the approximate capacitance of the membrane of this cell? You may treat it as a parallel plate capacitor. *(4 points)*

$A = \pi r^2$

$A = L\pi r^2$?

$C = K \varepsilon_0 \dfrac{A}{d}$

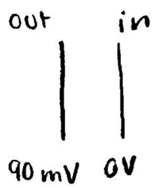
$C = \dfrac{(15)(8.85 \times 10^{-12})(2.52 \times 10^{-7})}{(5 \times 10^{-9})}$

$\boxed{C = 6.69 \times 10^{-9}}$

Please see last page!

(c) The electric potential inside the cell is 90 mV lower than the electric potential outside the cell. What is the total amount of charge separated across this nerve cell membrane and what is the total electric energy stored on this membrane capacitor? *(4 points)*

Inside = 0 V   Outside = 90×10^{-3} V



To find charge:

$$Q = C \cdot V = (6.69 \times 10^{-9})(90 \times 10^{-3} \text{ V}) = \boxed{6.02 \times 10^{-10} \text{ C}}$$

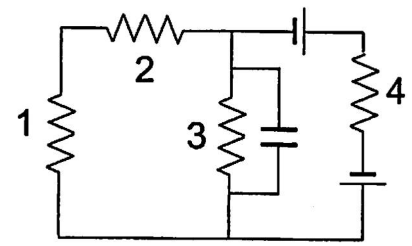
To find electric energy:

$$U = \frac{1}{2} C V^2 = \frac{1}{2}(6.69 \times 10^{-9})(90 \times 10^{-3})^2 = \boxed{2.71 \times 10^{-11} \text{ J}}$$

Problem 3

(12 points)

Consider the circuit shown below with two 24 V batteries, four identical 120 Ω light bulbs, and one 300 nF capacitor.



$V = 48\ V$

$R = 120\ \Omega$

$C = 300 \times 10^{-9}\ F$

(a) Calculate the electric power dissipated in resistor 4. *(6 points)*

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

$V = R \cdot I$

$R_{12} = 240\ \Omega$ $\quad R_{123} = 80\ \Omega$ $\quad R_{tot} = 200\ \Omega$

$R_{tot} = 200\ \Omega$	$I_{tot} = 0.24\ A$	$V_{tot} = 48\ V$
$R_4 = 120\ \Omega$	$I_4 = 0.24\ A$	$V_4 = 28.8\ V$
$R_{123} = 80\ \Omega$	$I_{123} = 0.24\ A$	$V_{123} = 19.2$
$R_3 = 120\ \Omega$	$I_3 = 0.16\ A$	$V_3 = 19.2$
$R_{12} = 240\ \Omega$	$I_{12} = 0.08\ A$	$V_{12} = 19.2$
$R_1 = 120\ \Omega$	$I_1 = 0.08\ A$	$V_1 = 9.6\ V$
$R_2 = 120\ \Omega$	$I_2 = 0.08\ A$	$V_2 = 9.6\ V$

$P = I \cdot V \rightarrow P_4 = 0.24\ A \cdot 28.8\ V = \boxed{6.91\ W}$

(b) Calculate the charge on the capacitor. *(6 points)*

$C = \frac{Q}{V} \rightarrow Q = C \cdot V$ ← @ steady state

$C = 300 \times 10^{-9}$ F $\quad V_3 = 19.2$ V

↑ has to only be V that R_3 sees

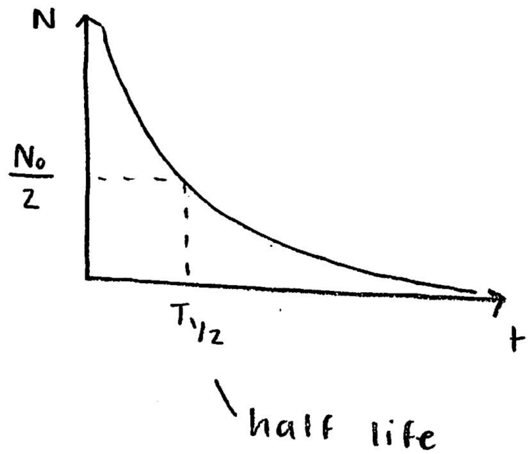
$Q = (300 \times 10^{-9} \text{ F})(19.2 \text{ V}) = \boxed{5.76 \times 10^{-6} \text{ C}}$

↑ found this in part a

Problem 4 — $T_{1/2}$ (12 points)

Carbon-14 is a beta emitter with a half life of 5730 years.

(a) Draw a plot that shows how the number of atoms in a radioactive sample varies over time and label the half life. *(3 points)*



(b) Write down all the decay products of the reaction. *(3 points)*

α decay: ${}^{14}_{4}C \rightarrow {}^{4}_{2}He + {}^{10}_{2}X$

β-decay: ${}^{14}_{4}C \rightarrow {}^{14}_{5}X + e^{-} + \bar{\nu}_e$

${}^{14}_{4}C \rightarrow {}^{14}_{3}X + e^{+} + \nu_e$

γ-decay: ${}^{14}_{4}C^{*} \rightarrow {}^{14}_{4}C + \gamma$

(c) The ratio between stable and radioactive carbon in the atmosphere is constant at one part per trillion ($N_{C12,0}/N_{C14,0} = 10^{12}$). You analyze the bone of a paleolithic mammoth and find a ratio of N_{C12}/N_{C14} to be 10^{15}. How many years ago did the animal die? *(6 points)*

$\frac{C_{12}}{C_{14}} = 10^{15}$ so $\frac{C_{14}}{C_{12}} = 10^{-15}$ $T_{1/2} = 5730$ years

$\lambda = \frac{\ln(2)}{T_{1/2}} = \frac{\ln(2)}{5730} = 1.2 \times 10^{-4}$

radiocarbon dating formula

$t = \frac{-1}{\lambda} \ln\left(\frac{C_{14}}{C_{12}} \cdot 10^{12}\right)$

$t = \frac{-1}{1.2 \times 10^{-4}} \ln\left(10^{-15} \cdot 10^{12}\right) = 57564 = 5.8 \times 10^4$ years

The animal died 5.8×10^4 years ago.