2021 Shardhunt Physics Challenge: Answer Key

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2021 Shardhunt Physics Challenge Answer Key: Section A

A1 Etienne and Joseph launch their manned hot air balloon from the ground at a speed of 3.5 m/s. If the balloon only travels directly upwards and isn't accelerating, how many meters high will it be after 8.5 minutes?

Answer:

$$v = \frac{d}{t}$$

$$3.5 \text{ m/s} = \frac{d}{8.5 \text{ minutes} * 60}$$

$$d = 1785 \text{ m}$$

A2 Ferdinand's rigid airship starts at rest and accelerates at a constant rate of 5 m/s over a lake. If the lake is 362,902.5 meters across, how fast is the airship traveling when it reaches the opposite bank?

Answer:

$$v_f^2 = v_i^2 + 2ad$$

$$v_f^2 = 0^2 + 2(5 \text{ m/s}^2)(362902.5 \text{ m}) = 3629025 \text{ m}^2/\text{s}^2$$

$$v_f = 1905 \text{ m/s}$$

A3 Orville and Wilbur's flier has a mass of 476 kg. Given that it accelerates at 4 m/s^2, how much net force is being applied to the flier?

Answer:

$$F = ma$$

$$F = (476 \text{ kg})(4 \text{ m/s}^2)$$

$$F = 1904 \text{ N}$$

A4 How heavy is Tony's commercial flight if it has 2,395,000 Joules of kinetic energy while traveling at 50 m/s?

Answer:

$$K = \frac{1}{2}mv^2$$

$$2395000 \text{ J} = \frac{1}{2}m(50\text{m/s})^2$$

$$m = 1916 \text{ kg}$$

A5 Lowell, Leslie, Eric, and John are trying to figure out the fastest way to complete their circumnavigation of the world. What's the furthest distance they can travel between stops given that the fuel tank holds 214 liters of fuel, and each liter allows the plane to fly at 150 m/s for one minute? Give your answer in kilometers.

Answer:

$$d = vt$$
$$t = (60 \text{ s/L})(214 \text{ L}) = 12840 \text{ s}$$
$$d = (150 \text{ m/s})(12840 \text{ s}) = 1926000 \text{ m}$$
$$d = 1926 \text{ km}$$

A6 In flying from Norway to the North Pole, the density of the air around Richard's airplane increases by 25%. If the lift force in Norway was 1,541.6 N, and no other variables have changed, what is the lift force over the North Pole?

Answer (note that lift is linearly proportional to the density of the air):

$$L_f = 1.25L_i$$
$$L_f = (1.25)(1541.6 \text{ N})$$
$$L_f = 1927 \text{ N}$$

2021 Shardhunt Physics Challenge
Answer Key: Section B

B1 Charles flies 5,790 km from New York to Paris. If each liter of fuel allows him to travel 3 km, and he has exactly enough fuel for his journey, how many liters of fuel is he carrying when he starts?

Answer:

$$fuel = \frac{d}{3 \text{ km/L}}$$

$$fuel = \frac{5790 \text{ km}}{3 \text{ km/L}}$$

$$fuel = 1930 \text{ L}$$

B2 Max's zeppelin catches fire, increasing the temperature of the surrounding 380 kilograms of air by 5.088° Celsius. Given that the specific heat capacity of air is 1.005 J/kg·C, how much energy is transferred to the air?

Answer:

$$Q = mc\Delta T$$

$$Q = (380 \text{ kg})(1.005 \text{ J/kg})(5.088 \text{ °C})$$

$$Q = 1943.1072 \text{ J} \approx 1943 \text{ J}$$

B3 What is the lift acting on Amelia's ill-fated airplane, given that the density of the air in New Guinea is 1.225 kg/m^3, the wings of the airplane have a surface area of 2.5 m^2 and a lift coefficient of 0.25, and the plane is traveling at 71.207 m/s?

Answer:

$$L = \frac{1}{2} C_L \rho A v^2$$

$$L = \frac{1}{2}(0.25)(1.225 \text{ kg/m}^3)(2.5 \text{ m}^2)(71.207 \text{m/s})^2$$

$$L = 1941.0266 \text{ N} \approx 1941 \text{ N}$$

B4 Chuck's 67,500 kg aircraft experiences a forward thrust of 13000 N and a drag force of 1145.161 N. Starting from rest, how long does it take him to break the sound barrier of 343 m/s?

Answer:

$$F_{net} = F_{thrust} - F_{drag}$$

$$F_{net} = ma$$

$$F_{thrust} - F_{drag} = ma$$

$$a = \frac{\Delta v}{t}$$

$$F_{thrust} - F_{drag} = m\frac{\Delta v}{t}$$

$$13000 \text{ N} - 1145.161 \text{ N} = (67500 \text{ kg})\frac{343 \text{ m/s}}{t}$$

$$t = 1953 \text{ s}$$

B5 What is the tangential velocity of Mikhail's satellite if it has a centripetal acceleration of 0.5903 m/s^2 and orbits at 150 kilometers above the equator of the earth?

Answer:

$$a_c = \frac{v^2}{r}$$

$$0.5903 \text{ m/s}^2 = \frac{v^2}{6378000 \text{ m} + 150000 \text{ m}}$$

$$v = 1963.028 \text{ m/s} \approx 1963 \text{ m/s}$$

B6 Yuri launches in a spacecraft with a dry mass of 344.452 kg and a wet mass of 4,725 kg. Given an effective exhaust velocity of 750 m/s, what is the maximum velocity the rocket can achieve?

Answer (using the ideal rocket equation):

$$\Delta v = v_e \ln \frac{m_{wet}}{m_{dry}}$$

$$\Delta v = (750 \text{ m/s})(\ln \frac{4725 \text{ kg}}{344.452 \text{ kg}})$$

$$\Delta v = 1964.001 \text{ m/s} \approx 1964 \text{ m/s}$$

2021 Shardhunt Physics Challenge
Answer Key: Section C

C1 Neil's rocket weighs 335.75 tons on the Moon. Given that the moon's gravitational field is 17% of Earth's, how many tons would it weigh at Cape Canaveral?

Answer:

$$W = mg$$
$$m = \frac{W}{g}$$
$$\frac{W_{moon}}{0.17g_{earth}} = \frac{W_{earth}}{g_{earth}}$$
$$W_{earth} = \frac{335.75 \text{ tons}}{0.17}$$
$$W_{earth} = 1975 \text{ tons}$$

C2 JPL's first interstellar probe needs to travel at 11000 m/s to escape Earth's gravity. Given a dry mass of 8,104.068 kg and an effective exhaust velocity of 2000 m/s, give the total wet mass needed for the rocket, in thousands of kilograms.

Answer (using the ideal rocket equation):

$$\Delta v = v_e \ln \frac{m_{wet}}{m_{dry}}$$
$$11000 \text{ m/s} = (2000 \text{ m/s})(\ln \frac{m_{wet}}{8104.068 \text{ kg}})$$
$$m_{wet} = 1982998.1 \text{ kg} \approx 1982 \text{ Mg}$$

C3 Dick and Jeana are carrying exactly enough fuel to travel the circumference of the world without pausing. Given that one liter of fuel allows them to travel 151.11 kilometers, and each liter of fuel weighs 0.75 kg, calculate the lift force needed to counter the weight of the airplane's fuel tank.

Answer:

$$fuel = \frac{40075 \text{ km}}{151.11 \text{ km/L}} = 265.222 \text{ L}$$
$$m_{fuel} = (265.222 \text{ L})(0.75 \text{ kg/L}) = 198.92 \text{ kg}$$
$$F_g = mg$$
$$F_g = (198.92 \text{ kg})(10 \text{ m/s}^2)$$
$$F_g = 1989.163 \text{ N} \approx 1989 \text{ N}$$

C4 What is the rotational inertia of Edwin's namesake telescope if it has a rotational kinetic energy of 175.96 Joules and is traveling at an angular velocity of 0.42 rad/s?

Answer:

$$W = \frac{1}{2}I\omega^2$$

$$175.96 \text{ J} = \frac{1}{2}I(0.42 \text{ rad/s})^2$$

$$I = 1995.011 \text{ kg·m}^2 \approx 1995 \text{ kg·m}^2$$

C5 What is the centripetal acceleration of a multi-nation space station if it orbits at 6,551 km above the center of the Earth, with a velocity of 3619.67 km/s? Give your answer in km/s^2.

Answer:

$$a_c = \frac{v^2}{r}$$

$$a_c = \frac{(3619.67 \text{ km/s})^2}{6551 \text{ km}}$$

$$a_c = 2000.017 \text{ kg/s}^2 \approx 2000 \text{ kg/s}^2$$

C6 NASA's ingenious helicopter flies for the first time at 295.62 m above the surface of Mars, which has a gravitational field of 3.8 m/s^2. If the helicopter weighs 1.8 kg, what is the gravitational potential energy of the craft?

Answer:

$$U = mgh$$

$$U = (1.8 \text{ kg})(3.8 \text{ m/s}^2)(295.62 \text{ m})$$

$$U = 2022.0408 \text{ J} \approx 2022 \text{ J}$$

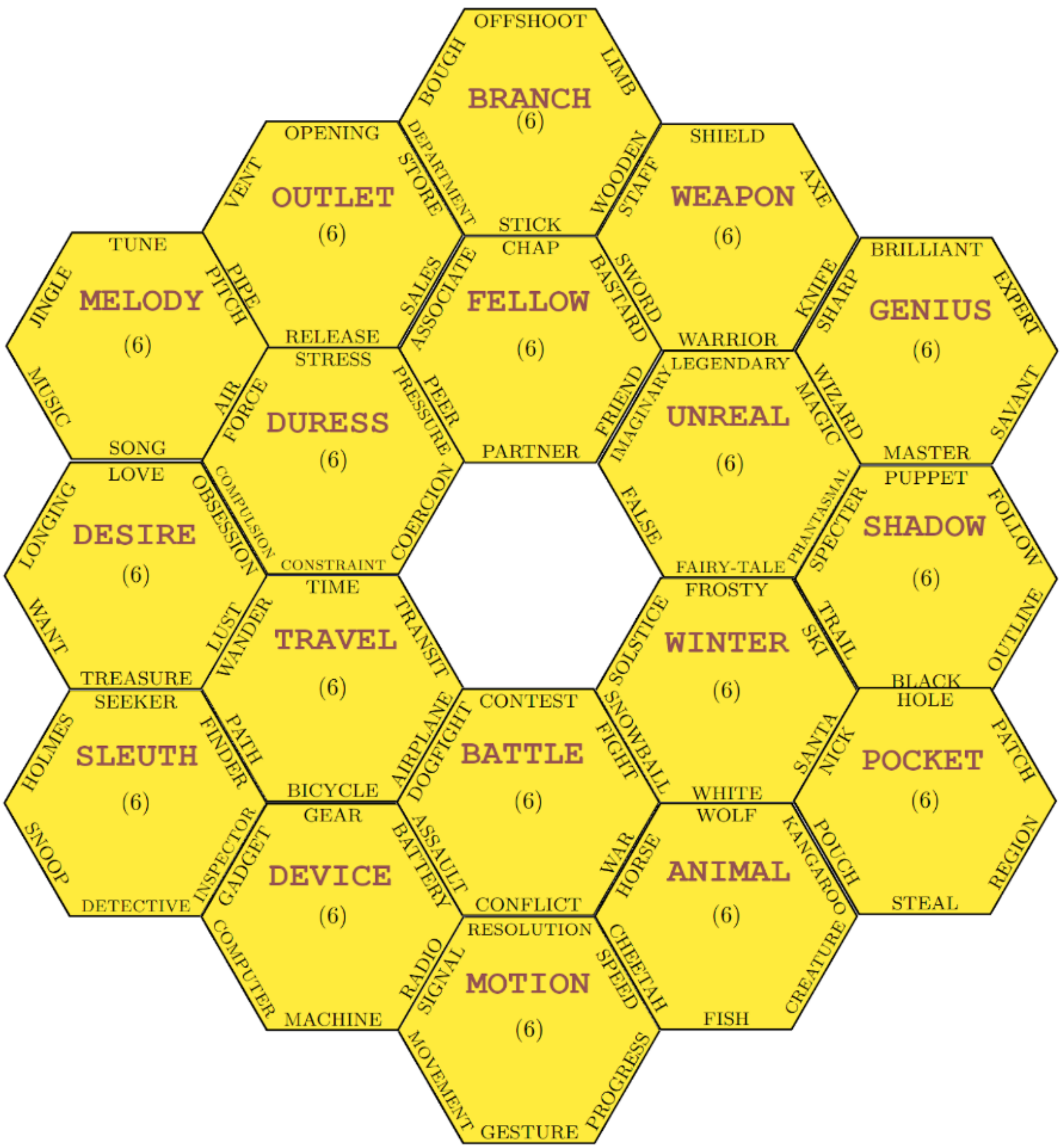
2021 Shardhunt Physics Challenge Answer Key: Notes on Sections A-C

At this point, test-takers should realize that each physics problem appears to be resolving to a year. Each problem describes an event from the history of aviation and spaceflight, but the year that the event happened is between 1 and 6 years before the answer to the problem - indicating that the launch has been ”delayed.”

#	Problem	Event	Event Year	Answer	Delay
A1	Etienne and Joseph launch a hot air balloon from the ground...	First flight in a hot air balloon	1783	1785	2
A2	Ferdinand's rigid airship...	First zeppelin flight	1900	1905	5
A3	Orville and Wilbur's flyer...	First powered flight (Wright brothers)	1903	1904	1
A4	...Tony's commercial flight...	First commercial flight	1914	1916	2
A5	Lowell, Leslie, Eric, and John are trying to figure out the fastest way to complete their circumnavigation of the world...	First circumnavigation of the world (with stops) by plane	1924	1926	2
A6	In flying from Norway to the North Pole, the density of the air around Richard's airplane...	First flight over the north pole	1926	1927	1
B1	Charles flies 5,790 km from New York to Paris...	First nonstop trans-atlantic flight	1927	1930	3
B2	Max's zeppelin catches fire...	Hindenburg disaster	1937	1943	6
B3	...Amelia's doomed airplane...	Amelia Earhart vanishes	1937	1941	4
B4	Chuck's 67,500 kg aircraft...break[s] the sound barrier...	Sound barrier is broken	1947	1953	6
B5	...Mikhail's satellite...	First satellite in space	1957	1963	6
B6	Yuri launches in a spacecraft...	First person in space	1961	1964	3
C1	Neil's rocket...on the moon...	First people on the moon	1969	1975	6
C2	One of JPL's two probes bound for deep space...	Voyager crafts launched	1977	1983	6
C3	Dick and Jeana are carrying exactly enough fuel to travel the circumference of the world without pausing...	First nonstop flight around the world	1986	1989	3
C4	...Edwin's namesake telescope...	Hubble space telescope launched	1990	1995	5
C5	...a multi-nation space station...	ISS launched	1998	2000	2
C6	NASA's ingenious helicopter flies for the first time...	Ingenuity flies on Mars	2021	2022	1

2021 Shardhunt Physics Challenge Answer Key: Section ⬢

Now test-takers can turn their attention to the hexagons in the final section of the test. There are two key mechanics to identify here. The first is that the words around the edge of each hex all clue a specific 6-letter word. The second is that the words at the edges of the hexagons can be paired up with each other to form phrases such as "black hole" or "snowball fight". Matching up these word pairs allows solvers to assemble the hexagons into a larger hexagonal grid, with a single word in the center of each. The completed grid is displayed below (credit for the very nice image goes to our test-test-takers from Please Clap).



2021 Shardhunt Physics Challenge Answer Key: Notes on Section ⬣

Now we have a very distinctive grid of yellow hexagons. Some test-takers may be able to recognize this as the James Webb Space Telescope mirror layout immediately. Otherwise, the telescope can be found by googling spaceflight launches that involve hexagons, or by realizing that the year of the physics exam also indicates the year that JWST launched. Now test-takers can associate physics problems with hexes by finding that the JWST mirrors are labelled in "A" "B" and "C" sections of 6 mirrors each. This can be done with the following layout (image credit: NASA).

At this point it is the simple matter to index into the word at the center of each hexagon with the delay obtained from the physic problems. Reading the letters in a clockwise spiral results in ANSW: KINCHELOE AWARD.

2021 Shardhunt Physics Challenge Answer Key: Author's Notes

Ella: It may not surprise to learn that the launch of this puzzle was, in fact, delayed. This was one of the first puzzles that I wrote for the hunt (the first one that I wrote that actually made it into the final hunt, at least), and it was written shortly after the successful launch of JWST in December 2021. Those of you who were following space news at the time will remember the endless chain of delays leading up to the actual launch - in fact, the first proposal for JWST originally had it launching no later than 2007. This puzzle is deliberately poking some good-spirited fun at this fact - and I hope that my fellow space nerds among the solvers found this as funny as I did.

Given the hexagonal theme of our hunt, it was inevitable that I had to write a JWST puzzle. Those who know me can attest that I am a huge fan of this telescope, and talked about it incessantly before (and after) the launch. I wasn't the only one with this idea, either - Yanaphat ended up collaborating on this puzzle after we realized that we were both independently working on a JWST puzzle! The final version of this puzzle didn't end up looking very much like the one he had planned - I believe some of his ideas ended up getting incorporated into Babelbees instead - but he should be thanked as providing the impetus for the hex grid assembling step, as well as the beautiful Latex formatting. Also, a big thank you to Mitchell for the long hours spent brainstorming mechanics together, and to Julie for helping me through the very constrained hex grid construction.

Ultimately, I am very pleased with how this puzzle came out. I hoped that this puzzle would have something appealing for a range of people, whether they are physics enjoyers or not. (In fact, the physics problems were deliberately kept simple so that it would be accessible to as many people as possible.) The only step that I refused to nerf was the final extraction step of identifying the JWST mirror layout and finding the mirror numbers. The JWST aha is my favorite part of the puzzle, and I didn't want to cheapen it with obvious hinting. I just hope people came away from the puzzle with an increased appreciation for JWST, the history of aviation and spaceflight, or both!

Yanaphat: Initially, I planned to write a puzzle named Jigsaws With Six Triangles, which had the same mechanics as the hexagon assembling part of this puzzle, but use colors instead of words, before realizing that there was already a JWST puzzle in progress. Words connection was a much better mechanics, and also much more constrained. I was very grateful that Ella and Julie could actually pull it off. In hindsight, this allowed me to use hex code in Bablebees, so it was better all around.

This puzzle started out as a google document and I thought it would be more thematic as a PDF than a HTML, so I set aside three days just to learn LaTeX and tikz package. I ended up reading TEX stack exchange posts and copy-pasting a bunch of code snippets without fully understand how they work, but it was enough to create the decent-looking headers and hexagons that you all see in this puzzle. I would like to thank Adeline and Ella who helped with checking and putting the finishing touch to the LaTex file. I hope you like how it turned out.