PHYSICS 116 PRACTICE EXAM 3B

Seat No_________

Last Name (Print): ______________________ First Name (Print): _____________________

Honor Pledge: *All work presented here is my own.*

Signature: ______________________________ Student ID: _________________________

READ THIS ENTIRE PAGE NOW
Do not open the exam until told to do so.
You will have 110 minutes to complete the examination.

NO CELL PHONES, TEXT MSG, etc. ALLOWED AT ANY TIME.

Before the exam begins:

- Print and sign your name, and write your student ID number in the spaces above.

During the exam

- When the exam begins, print your name and student ID number on the top of each page. Do this first when you are told to open your exam.
- If you are confused about a question, raise your hand and ask for an explanation.
- If you cannot do one part of a problem, move on to the next part.
- This is a closed book examination. All equations and constants are provided.
- You may use a calculator, but not a computer, or other internet connected devices (smart-phones, iPads, etc.).

For multiple-choice questions:

- Clearly circle your answer choice. Make no stray marks. If you must erase, erase completely.

End of exam:

- Out of respect to other students, please remain seated for the last 20 minutes of the exam.
  At the end of the exam, please remain seated until all exams have been collected

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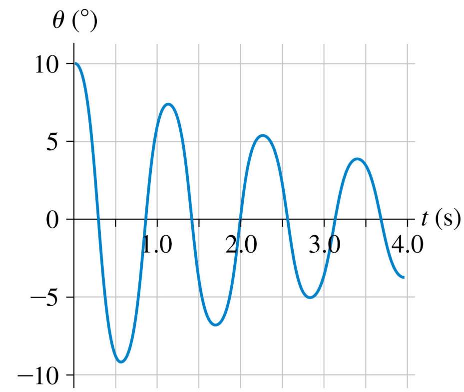
Answer Questions 1 through 16 on your scantron form. Fill in the bubble(s) corresponding to the correct answer fully and erase marks of unwanted choices. Only one choice is correct. Please write your name on ALL the paper you use.

1. [5 pts] The graph at right shows the angular oscillation of a damped pendulum with time. Estimate the time constant for this damped oscillation.
   a. 0.3 s
   b. 1.2 s
   c. 2.5 s
   d. 3.6 s
   e. $\boxed{4.3 \text{ s}}$



Solution:
Starting with $\theta(t) = \theta_0 e^{-t/\tau}$, we notice that $\theta_0 = 10°$.
When $t = 2.5$ s, the value of θ drops to about 5.5°.
Therefore:

$$\theta(t) = \theta_0 e^{-t/\tau} \Rightarrow \tau = \frac{t}{-\ln\left(\frac{\theta(t)}{\theta_0}\right)} = \frac{2.5 \text{ s}}{-\ln\left(\frac{5.5}{10}\right)} = 4.2 \text{ s}$$

2. [5 pts] When the standing wave pattern in a pipe is NANA, the pipe has which of the following set of properties? (N stands for node, A for antinode.)
   a. It is open at both ends.
   b. It is closed at both ends.
   c. $\boxed{\text{It is open at one end and closed at the other end.}}$
   d. Any of the above could be true.

Solution:
The wave in a pipe is a sound wave in which pressure varies, an open pipe would have a node at the point in contact with the outside, since the air outside would have a pressure that equals atmospheric pressure, and because the pattern given includes a node at one end it must be exposed to the outside, the other end is an antinode, and that's consistent with the closed end, where pressure varies between the maximum below (trough) and the maximum above (crest) atmosphere.

3. [5 pts] Unpolarized light of intensity $2.0 \times 10^{-2} \text{W/m}^2$ is incident on a polarizer sheet whose axis is aligned vertically, then light passes through an analyzer (a second polarizer sheet) whose axis makes an angle of 25° above the horizontal. What's the intensity that passes through the combination?
   a. $0.42 \times 10^{-2} \text{W/m}^2$
   b. $0.36 \times 10^{-2} \text{W/m}^2$
   c. $1.6 \times 10^{-2} \text{W/m}^2$
   d. $0.82 \times 10^{-2} \text{W/m}^2$
   e. $\boxed{0.18 \times 10^{-2} \text{W/m}^2}$

Solution:
Since light entering the polarizer is initially unpolarized, its intensity would be reduced to half the unpolarized intensity and the emerging light would polarized along the axis of the polarizer.

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$$I_1 = \frac{I_0}{2}$$

Then as it passes through the second polarizer, the intensity would drop according to Malus' law:

$$I_2 = I_1 \cos^2\theta = \frac{I_0}{2}\cos^2(90^\circ - 25^\circ) = \frac{2.0 \times 10^{-2}\,\mathrm{W/m^2}}{2}\cos^2 65^\circ = \boxed{0.18 \times 10^{-2}\,\mathrm{W/m^2}}$$

4. [5 pts] A ray of light is incident on the mid-point of a glass prism surface at an angle of 25.0° with the normal. For the glass, *n* = 1.55, and the prism apex angle is 30.0°. What is the angle of refraction as the ray enters the air on the far side of the prism?
   a. 14.1°
   b. $\boxed{22.3^\circ}$
   c. 28.4°
   d. 46.0°

Solution:

First refraction (air to glass):

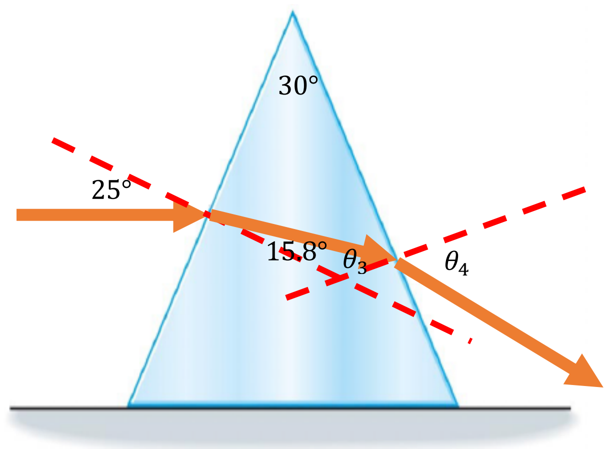
$$1 \sin 25^\circ = 1.55 \sin\theta_2 \Rightarrow \theta_2 = 15.8^\circ$$

To find the angle of incidence θ_3 we use the fact that for a triangle:

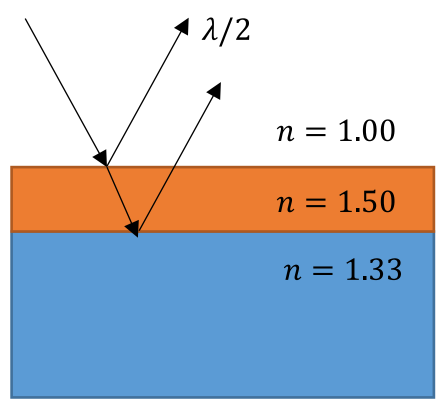
$$180^\circ = 30^\circ + (90^\circ - 15.8^\circ) + (90 - \theta_3) \Rightarrow \theta_3 = 14.2^\circ$$

Second refraction (glass to air):

$$1.55 \sin 14.2^\circ = 1 \sin\theta_4 \Rightarrow \theta_4 = 22.3^\circ$$



5. [5 pts] A researcher measures the thickness of a layer of benzene ($n = 1.50$) floating on water ($n = 1.33$) by shining monochromatic light onto the film and varying the wavelength of the light. She determines the thickness to be 120 nm. What is the largest wavelength (measured in vacuum) that is reflected most strongly from the film?
   a. 90 nm
   b. 320 nm
   c. 370 nm
   d. 640 nm
   e. $\boxed{720\text{ nm}}$



Solution:

Reflection off of the benzene layer will cause a half-wavelength phase change upon reflection (lower to higher index of refraction transition), but from the benzene to water no half-wavelength phase change occurs. To get constructive inteference for reflected light, the total path difference must be an integer multiple of wavelength within the benzene:

$$\Delta r = 2t + \frac{\lambda_{\text{benzene}}}{2} = \lambda_{\text{benzene}} m \Rightarrow 2t = \lambda_{\text{benzene}}\left(m - \frac{1}{2}\right)$$

Solving for wavelength:

$$\lambda_{\text{benzene}} = \frac{2t}{\left(m - \frac{1}{2}\right)}$$

Maximizing wavelength happens when the denominator is minimized, i.e. when $m = 1$:

$$\lambda_{\text{benzene}} = 4t = \frac{\lambda_{\text{vacuum}}}{n_{\text{film}}} \Rightarrow \lambda_{\text{vacuum}} = 4tn_{\text{film}} = 4 \times (120\text{ nm})(1.50) = \boxed{720\text{ nm}}$$

6. A container of water ($n = 1.333$) has a flat layer of ice on top ($n = 1.309$) of it. If a beam of light originates from the water, what's the minimum angle of incidence on the ater-ice-interface would no light penetrate through the ice?
   a. 89.53°
   b. $\boxed{79.11°}$
   c. 41.17°
   d. 37.03°
   e. The situation described is not possible.

Solution

We are looking here for the critical angle for TIR to happen. Since $n_{water} > n_{ice}$ we will have TIR for angles equal to or greater than θ_c:

$$\theta_c = \sin^{-1}\left(\frac{1.309}{1.333}\right) = 79.11°$$

7. [5 pts] A candle with a height of 20 cm is 50 cm from a concave mirror with a focal length of 30 cm. Determine the height and orientation of the image of the candle.
   a. $\boxed{\text{30 cm and inverted}}$
   b. 0.38 cm and upright
   c. 0.38 cm and inverted
   d. 7.5 cm and upright
   e. 7.5 cm and inverted

Solution:

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \Rightarrow s' = \frac{sf}{s-f} = \frac{(50\text{ cm})(30\text{ cm})}{(50\text{ cm} - 30\text{ cm})} = 75\text{ cm}$$

$$m = -\frac{s'}{s} = -\frac{75\text{ cm}}{50\text{ cm}} = -1.5 = \frac{h'}{h} \Rightarrow h' = -1.5 \times 20\text{ cm} = \boxed{-30\text{ cm}}$$

The image is inverted, since the magnification is negative, and the image has a height of 30 cm.

8. [5 pts] Light with a frequency of 5.3×10^{14}Hz illuminates one narrow slit with a width of 1.7×10^{-6}m. How many bright fringes are produced?
   a. None.
   b. 3
   c. 4
   d. $\boxed{5}$
   e. 6

Solution:

$$a \sin\theta_p = p\lambda \Rightarrow \sin\theta_p = \frac{p\lambda}{a} = \frac{pc}{af} = p \times \frac{3.0 \times 10^8 ms}{(1.7 \times 10^{-6}\text{m})(5.3 \times 10^{14}\text{Hz})} = 0.333\,p$$

If $p = 1 \Rightarrow \sin\theta_1 = 0.333$. If $p = 2 \Rightarrow \sin\theta_2 = 0.666$. If $p = 3 \Rightarrow \sin\theta_3 = 0.999$, after that the sine would exceed one, so, we wouldn't get more fringes. p represents dark fringes, the first set with $p = 1$ occur on either side of the central bright fringe, the second set occurs after the next bright fringe and the third set after the next one, thereby enclosing a total of 5 bright fringes.

Use the following situation to answer the next two questions
Alicia wears corrective lenses with a refractive power of –1.5.

9. [5 pts] Based on the refractive power of her lenses, which of the following problems can you conclude that her eyes may have?
   a. The ability of her eyes' ciliary muscle to shorten their lens' focal length is impaired.
   b. Her eyeballs are too short; her eyes' lenses are too close to her retina.
   c. Her eyeballs are too long; her eyes' lenses are too far from her retina.
   d. She does not have enough rods or cones in her retina.
   e. More than one of the choices above could be her problem.

Solution:
A negative refractive power implies the patient has myopia; the image is formed in front of the lens because her eyeball is too long. The diverging lens would serve to push the position where focuses farther back towards the retina.

10. [5 pts] If an object is placed 2.5 m from her corrective lenses, where from the lens does the image form? Can this image be projected on a screen?
   a. 0.27 m, No
   b. 0.27 m, Yes
   c. 0.53 m, No
   d. 0.53 m, Yes
   e. 0.91 m, Yes

Solution:
$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} = P \Rightarrow s' = \frac{s}{Ps - 1} = \frac{2.5\text{ m}}{(-1.5\text{ m}^{-1})(2.5\text{ m}) - 1} = -0.53\text{ m}$$

11. [5 pts] A person has a near point of 1.5 m. What refractive power lenses would he need to focus on a newspaper held at a comfortable distance of 0.25 m?
   a. -3.3D
   b. -0.30D
   c. 0.21D
   d. 0.30D
   e. 3.3D

Solution:
The problem is that the near point is too big:
$$\frac{1}{1.5\text{ m}} + \frac{1}{s'_{ret}} = P_{eye}$$
We wish to have the near point corrected while not changing the distance of the image to the retina or the lens of the eye:
$$\frac{1}{0.25\text{ m}} + \frac{1}{s'_{ret}} = P_{eye} + P_{lens}$$
Subtracting the first equation from the second we get:
$$P_{lens} = \frac{1}{0.25} - \frac{1}{1.5} = 3.3\text{ D}$$

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Use the following scenario for the following two questions.
The work function of the metal in a photoelectric effect apparatus is 3.7×10^{-19}J. Monochromatic light with a frequency of 1.1×10^{15}Hz illuminates the cathode metal surface, causing electrons to be emitted.

12. [5 pts] What is the minimum wavelength of the ejected electrons? The mass of an electron is 9.1×10^{-31}kg. Hint: the kinetic energy of a particle, K, can be expressed in terms of its momentum, p, as $K = \frac{p^2}{2m}$, where m is the mass of the particle.
    a. Not applicable as electrons do not have wavelength.
    b. 5.8×10^{-10}m
    c. $\boxed{8.2 \times 10^{-10}\text{m}}$
    d. 1.2×10^{-10}m
    e. 2.7×10^{-10}m

Solution:
First we find the maximum kinetic energy of ejected electron:

$$E_{\text{photon}} = E_0 + K_{\max} \Rightarrow K_{\max} = E_{\text{photon}} - E_0 = hf - E_0$$
$$= (6.63 \times 10^{-34}\text{J}\cdot\text{s})(1.1 \times 10^{15}\text{Hz}) - 3.7 \times 10^{-19}\text{J} = 3.6 \times 10^{-19}\text{J}$$

Now we solve for the electron's momentum:

$$K_{\max} = \frac{p_{\max}^2}{2m} \Rightarrow p_{\max} = \sqrt{2mK_{\max}} = \sqrt{2 \times (9.1 \times 10^{-31}\text{kg})(3.6 \times 10^{-19}\text{J})}$$
$$= 8.1 \times 10^{-25}\text{kg}\cdot\text{m/s}$$

And finally, we solve for the electron's wavelength:

$$\lambda_{\min} = \frac{h}{p_{\max}} = \frac{6.63 \times 10^{-34}\text{J}\cdot\text{s}}{8.1 \times 10^{-25}\text{kg}\cdot\text{m/s}} = \boxed{8.2 \times 10^{-10}\text{m}}$$

13. [5 pts] If the intensity of the light hitting the cathode surface remains the same, but the frequency of the light shining on the cathode is increased, what will happen to the number and the maximum kinetic energy of ejected electrons?
    a. $\boxed{\text{Less electrons would be ejected, and the maximum kinetic energy of the ejected electrons would increase.}}$
    b. Less electrons would be ejected, and the maximum kinetic energy of the ejected electrons would decrease.
    c. More electrons would be ejected, and the maximum kinetic energy of the ejected electrons would increase.
    d. More electrons would be ejected, and the maximum kinetic energy of the ejected electrons would decrease.
    e. Fewer electrons would be ejected with the same maximum kinetic energy.

Solution:
Increasing the frequency, means fewer photons are hitting the cathode, since having the same intensity means the power sent hitting the same area doesn't change and now the share of each photon has increased. Each photon can cause the emission of exactly one electron, and since the number of photons dropped, so would the number of emitted electrons. However, each incident photon has more energy, and since the work function doesn't change, this means the emitted electrons would have more kinetic energy.

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14. [5 pts] A beam of electrons, a beam of protons, and a beam of oxygen atoms each pass at the same speed through a very narrow slit. Which will produce the widest diffraction central maximum?
    a. $\boxed{\text{The beam of electrons.}}$
    b. The beam of protons.
    c. The beam of oxygen atoms.
    d. All three patterns will be the same.
    e. None of the beams actually produce diffraction patterns.

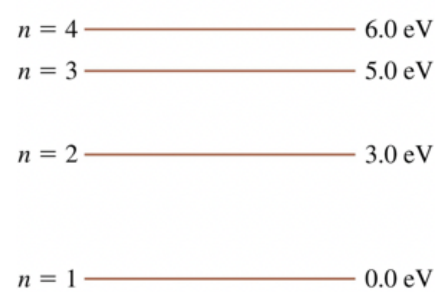
Solution:
From the de Broglie wavelength:

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Since $m_{\text{e}} < m_{\text{p}} < m_{\text{O}} \Rightarrow \lambda_{\text{e}} > \lambda_{\text{p}} > \lambda_{\text{O}}$
For a single-slit experiment:

$$w = \frac{2\lambda L}{a} \Rightarrow \boxed{w_{\text{e}} > w_{\text{p}} > w_{\text{O}}}$$

Use the following scenario for the following three questions. Consider a type of atoms with energy levels as shown at right.



15. [5 pts] What is the longest wavelength of light in the absorption spectrum of a gas of these atoms?
    a. $2.1 \times 10^{-7}\text{m}$
    b. $2.5 \times 10^{-7}\text{m}$
    c. $\boxed{4.1 \times 10^{-7}\text{m}}$
    d. $6.2 \times 10^{-7}\text{m}$
    e. $2.1 \times 10^{-6}\text{m}$

Solution:
The longest wavelength would correspond to the shortest energy separation between ground state and an excited state and that corresponds to the transition $1 \rightarrow 2$:

$$E = hf = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{(4.1 \times 10^{-15}\text{eV} \cdot \text{s})(3.0 \times 10^{8}\text{m/s})}{3.0\text{ eV}} = \boxed{4.1 \times 10^{-7}\text{m}}$$

16. [5 pts] A beam of electrons with 5.8 eV kinetic energy collides with a gas of these atoms in the ground state. What is the largest energy of photons in the emission spectrum?
    a. 2.0 eV
    b. 3.0 eV
    c. $\boxed{5.0\text{ eV}}$
    d. 5.8 eV
    e. 6.0 eV

Solution:
The atom can absorb only quantized amounts of energy to undergo jumps between levels. 5.8 eV would enable the atom to transition from ground to $n = 2$ and $n = 3$ but will not be enough to

reach $n = 4$. Therefore the maximum emission would be after the atom has been excited to $n = 3$ and has after that deexcited to $n = 1$, so that $E_{\text{photon}} = \Delta E = E_3 - E_1 = 5.0\text{ eV}$

17. [5 pts] The emission spectrum of a gas shows 15 lines. What is the minimum number of energy levels required to produce these 15 lines?
    a. 4
    b. 5
    c. $\boxed{6}$
    d. 10
    e. 15

    Solution:
    We can use transitions representing emissions of all possible energies and we can collect all energies transitions ending at the same level together, If we have 4 levels only (our lowest possible answer) then the transitions to the lowest level $n = 1$ will come from $n = 2, n = 3, n = 4$, which accounts for 3 lines. The next one is $n = 2$, the transitions to it will come from $n = 3, n = 4$, which is 2 lines. And lastly, for $n = 3$, the only possible transition is from $n = 4$. So, in total, we have 6. Doing the same for the next choice of 5, we get 10 lines, which doesn't work either. The next one over is 6, and that does work resulting in exactly 15. Other choices will obviously have more than 15.

Use the following scenario for the following three questions.
Consider an isotope of radon, ${}^{222}_{86}\text{Rn}$, which alpha-decays with a half-life of 3.8 days.

18. [5 pts] Compare the binding energy per nucleon of ${}^{222}_{86}\text{Rn}$ and that of the decay products. Which is larger?
    a. The binding energy per nucleon of ${}^{222}_{86}\text{Rn}$ is larger.
    b. $\boxed{\text{The binding energy per nucleon of the decay products is larger.}}$
    c. The binding energy per nucleon is the same for ${}^{222}_{86}\text{Rn}$ and its decay products.
    d. The answer depends on which daughter isotope is produced in the decay.

    Solution:
    When radon alpha-decays, energy is released, so the daughter nucleus would have more binding energy per nucleon, since, now we need to supply even more energy to break the smaller product.

19. [5 pts] How many neutrons are there in the nucleus of the daughter isotope?
    a. 84
    b. $\boxed{134}$
    c. 136
    d. 137
    e. 218

    Solution:
    For radon we had $N = A - Z = 222 - 86 = 136$ neutrons, when an alpha is emitted, we lose 2 neutrons so that we end up with 134 neutrons.

20. [5 pts] Suppose that you initially had a sample of 4.0 g of ${}^{222}_{86}\text{Rn}$ gas. What is the mass of the remaining ${}^{222}_{86}\text{Rn}$ gas after 4.5 days?
    a. 0.44g

b. 0.74g
c. $\boxed{1.8\text{g}}$
d. 2.0g
e. 3.4 g

Solution:

The number of undecayed atoms at any given time is given by:

$$N = N_0 e^{-\frac{\ln 2}{t_{1/2}}t} = N_0 \left(\frac{1}{2}\right)^{t/t_{1/2}}$$

The mass is proportional to the number of particles:

$$m = m_0 e^{-\frac{\ln 2}{t_{\frac{1}{2}}}t} = m_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{\frac{1}{2}}}}$$

$$\Rightarrow m(4.5\text{ days}) = 4.0\text{ g}\left(\frac{1}{2}\right)^{4.5/3.8} = \boxed{1.8\text{ g}}$$

21. [5 pts] A pure sample of ^{226}Ra contains 2.0×10^{14} atoms of the isotope. If the half-life of ^{226}Ra = 1.6×10^3 years, what is the decay rate of this sample?
    a. 2.7×10^{-12} Ci
    b. 3.4×10^{-10} Ci
    c. $\boxed{7.4 \times 10^{-8}\text{ Ci}}$
    d. 9.6×10^{-6} Ci

Solution:

$$R = \frac{N}{\tau} = \frac{N}{t_{1/2}/\ln 2} = \frac{2 \times 10^{14}\text{atoms}}{1.6 \times 10^3\text{yr}}\ln 2 = \frac{2 \times 10^{14}\text{atoms} \ln 2}{1.6 \times 10^3 \times 365 \times 24 \times 3600} = 2747\text{ Bq}$$

$$= 2747\text{ Bq} \times \frac{1\text{ Ci}}{3.7 \times 10^{10}\text{Bq}} = 7.4 \times 10^{-8}\text{Ci}$$

22. [5 pts] The Paschen series of hydrogen corresponds to electron transitions from higher levels to $n = 3$. What is the shortest wavelength in that series?
    a. $\boxed{820\text{ nm}}$
    b. 365 nm
    c. 1 094 nm
    d. 313 nm

    Solution:

    Shortest wavelength means largest energy, so we maximize the initial level, $n \to \infty$:

$$\lambda_\infty = \frac{91.1\text{ nm}}{\frac{1}{3^2} - \frac{1}{\infty}} = 820\text{ nm}$$

23. [5 pts] 1.2 Gy of gamma radiation are directed into 0.25 kg tumor. How much energy does the tumor absorb?
    a. 0.20J
    b. $\boxed{0.30\text{J}}$

c. 3.3J
d. 4.8J
e. 6.0 J

Solution:

RBE for γ is 1:

$$\text{dose in tissue} = \text{RBE} \times \text{dose} = 1 \times 1.2\ \text{Gy} = \text{Energy/mass}$$
$$\Rightarrow \text{Energy} = \text{dose} \times \text{mass} = 1.2 \times 0.25 = 0.3\ \text{J}$$

24. [5 pts] The person exposed to waste from a nuclear accident absorbs 0.30 J of energy from beta-decays of ^{90}Sr in their skeleton in 30 days. If the person's mass is 65 kg, and the skeleton forms 17% of the person's body mass, what dose equivalent in Sv will be received by the person's skeleton in the 30 days? The RBE of beta particles is 1.
    a. 0.0046 Sv
    b. $\boxed{0.027\ \text{Sv}}$
    c. 0.14 Sv
    d. 0.81 Sv
    e. 1.8 Sv

Solution:

For β, the RBE=1, therefore the dose in the tissue in Sv is energy/mass = $0.30\ \text{J}/(65\ \text{kg} \times 0.17) = 0.027\ \text{Sv}$