AP® Physics B
1999 Sample Student Responses

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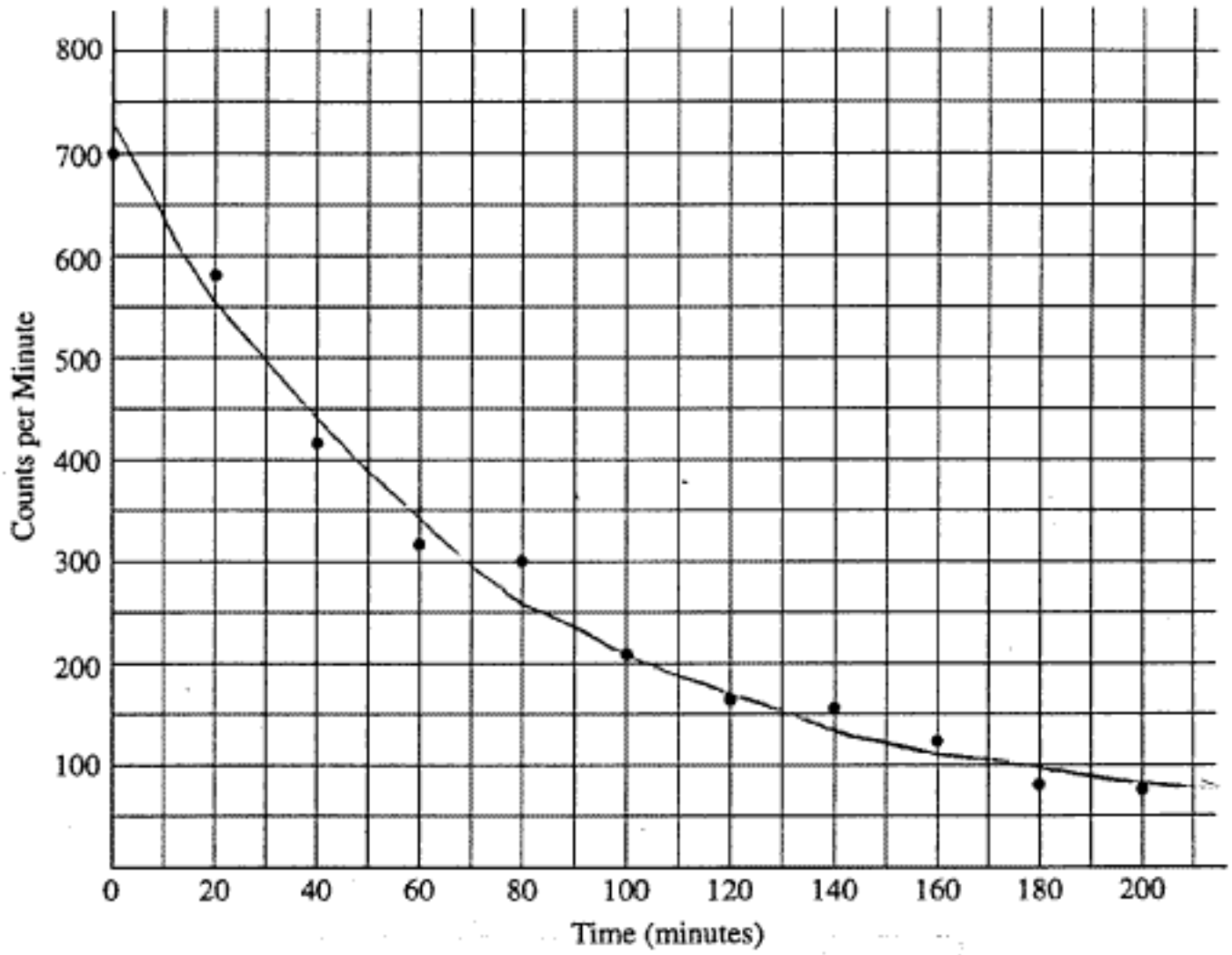
4. (15 points)
You use a Geiger counter to measure the decay of a radioactive sample of bismuth 212 over a period of time and obtain the following results.

Time (min)	0	20	40	60	80	100	120	140	160	180	200
Counts/minute	702	582	423	320	298	209	164	154	124	81	79

(a) Your results are plotted on the following graph. On the graph, draw an estimate of a best-fit curve that shows the radioactive counts as a function of time.



(b) From the data or from your graph, determine the half-life of this isotope. Explain how you arrived at your answer.

From 0 → 60 counts halved
From 80 → 140 counts halved
Thus half life = 60 minutes

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(c) The bismuth isotope decays into thallium by emitting an alpha particle according to the following equation:

$^{212}_{83}\text{Bi} \rightarrow \text{Tl} + \alpha$ $\quad {}^4_2He$ - 4 $\quad 212-4=208$ $\quad 83-2=81$

Determine the atomic number Z and the mass number A of the thallium nuclei produced and enter your answers in the spaces provided below.

$Z =$ 81 $\qquad A =$ 208

(d) The mass of the alpha particle is 6.64×10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.

i. Determine the momentum of the alpha particle. $\quad KE = \frac{1}{2}mv^2 \quad 1eV = 1.6\times10^{-19}J$

$p = mv$

$KE = 6.09\,MeV = 9.744\times10^{-13}\,J = \frac{1}{2}mv^2$

$1.949\times10^{-12} = mv^2 \Rightarrow \sqrt{v^2} = \sqrt{2.934\times10^{14}} \Rightarrow v = 1.713\times10^7$

$p = 6.64\times10^{-27}\,kg \times 1.713\times10^7 = 1.138\times10^{-19}\,kg\,m/s$

ii. Determine the kinetic energy of the recoiling thallium nucleus.

$p_\alpha = 1.138\times10^{-19}\,kg\,m/s$

$M_{thallium} =$ num protons & neutrons $\times$ mass $= 208\times1.67\times10^{-27} =$

$= 3.474\times10^{-25}$

$p_\alpha = p_{thallium} \quad 1.138\times10^{-19} = 3.474\times10^{-25}\times v$

$v = 3.276\times10^5 \quad KE = \frac{1}{2}mv^2 = 1.864\times10^{-14}$

(e) Determine the total energy released during the decay of 1 mole of bismuth 212.

$N_0 = 6.02\times10^{23}$

$\text{Total } E = (KE_\alpha + KE_{thallium}) \cdot N_0$

$\text{Total } E = 5.978\times10^{11}$

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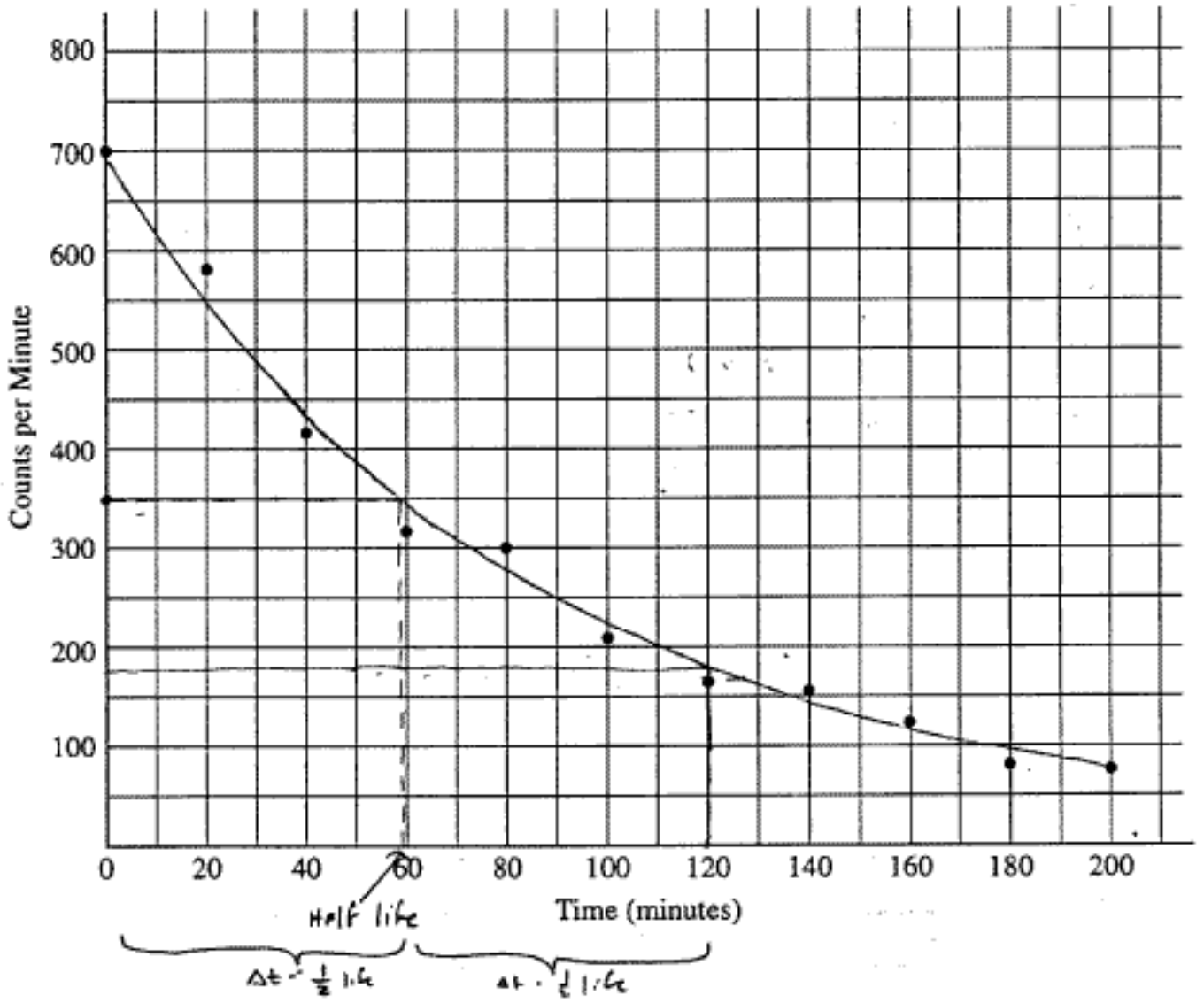

(b) From the data or from your graph, determine the half-life of this isotope. Explain how you arrived at your answer.

As the amount of a substance or amount of emmicions decreases by $\frac{1}{2}$ every half-life, on the graph, I plotted a horizontal line where half the total count is located. This is $\frac{702}{2}$, 350 minutes. I then looked at the corresponding time which is approximately 60 minutes which is the half life.

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(c) The bismuth isotope decays into thallium by emitting an alpha particle according to the following equation:

$$^{212}_{83}\text{Bi} \rightarrow \text{Tl} + \alpha$$

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$Z =$ 81 $\qquad A =$ 208

(d) The mass of the alpha particle is 6.64×10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.

i. Determine the momentum of the alpha particle.

$p = m \cdot v$

$m = 6.64 \times 10^{-27}$ kg

$K.E = 6.09\ \text{MeV} \times 10^{6} = 9.744 \times 10^{-13}$ J

$v = \sqrt{\frac{2(K.E)}{m}} = \sqrt{\frac{2(9.744 \times 10^{-13}\text{J})}{(6.64 \times 10^{-27}\text{kg})}}$ VELOCITY $= 1.713 \times 10^{7}\ \frac{m}{s}$

$p = (6.64 \times 10^{-27}\text{kg})(1.713 \times 10^{7})$

$p = 1.138 \times 10^{-19}\ \text{kg} \cdot \frac{m}{s}$

ii. Determine the kinetic energy of the recoiling thallium nucleus.

$(m_1 + m_2)v = m_1v_1' + m_2v_2'$

m_1 (Thallium) $= 208$ kg

m_2 (Alpha particle) $= 6.64 \times 10^{-27}$ kg

$m_1v_1' = m_2v_2'$

$208\text{kg} \cdot v_1 = 1.138 \times 10^{-19}\ \text{kg}\left(\frac{m}{s}\right)$

$v_{\text{Thallium}} = 5.47 \times 10^{-22}$ m/s

$KE = \frac{1}{2}mv^2 = \frac{1}{2}(208\text{kg})(5.47 \times 10^{-22}\frac{m}{s})^2$

$KE = 3.112 \times 10^{-41}$ Joules

(e) Determine the total energy released during the decay of 1 mole of bismuth 212.

TOTAL ENERGY = KINETIC ENERGY final − KINETIC ENERGY initial

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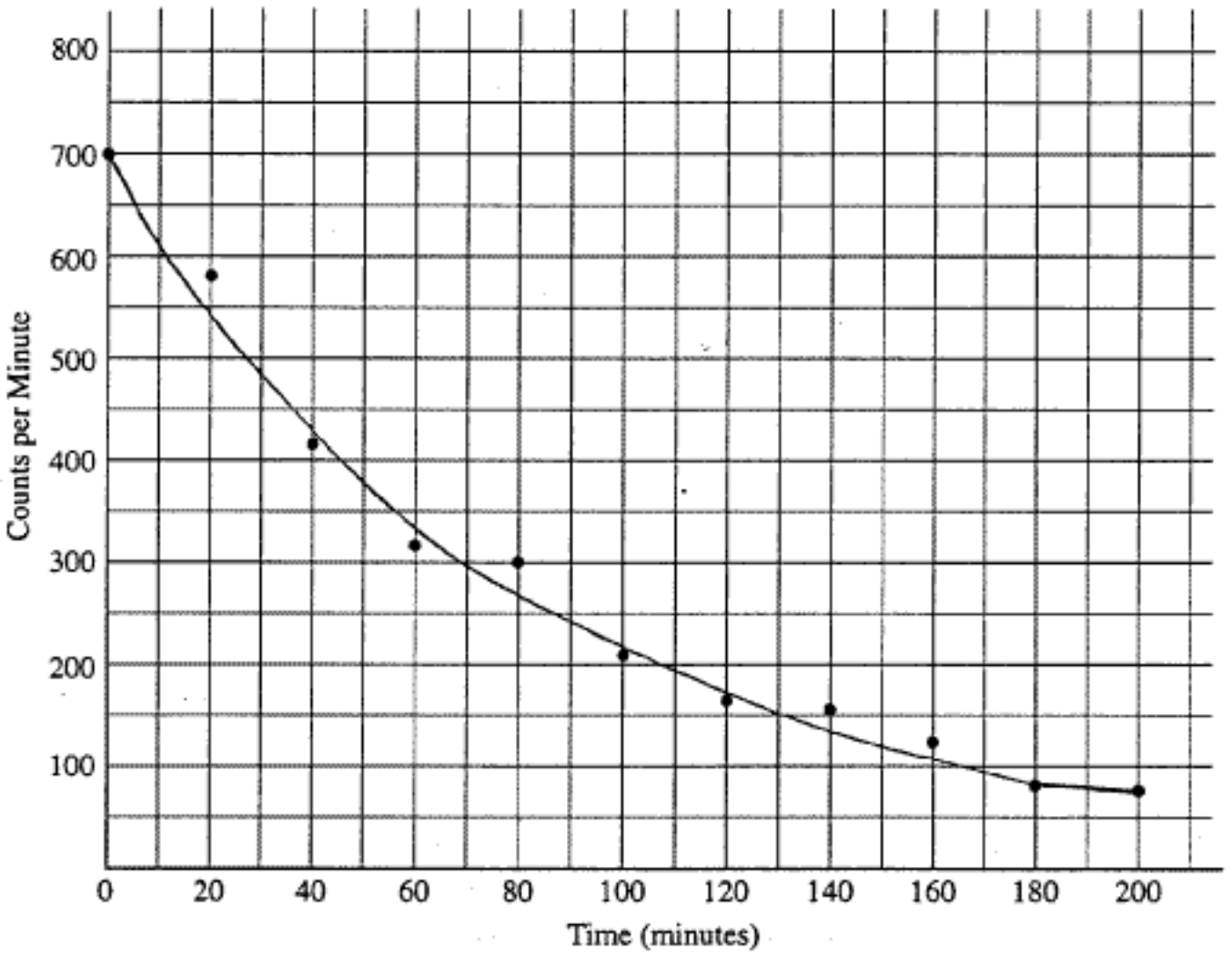

(b) From the data or from your graph, determine the half-life of this isotope. Explain how you arrived at your answer.

$\lambda N = \lambda N_0 e^{-\lambda t}$

$428 = 702 e^{-\lambda(40-0)}$

$\lambda = 0.0124$

$T_{1/2} = \frac{0.693}{\lambda}$

$= 56$ min

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$Z =$ 208 $\qquad A =$ 81

(d) The mass of the alpha particle is 6.64×10^{-27} kg. Its measured kinetic energy is 6.09 MeV and its speed is much less than the speed of light.

i. Determine the momentum of the alpha particle.

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

$(6.09\times10^{6})(1.60\times10^{-19}) = \frac{1}{2}(6.64\times10^{-27})v^2$

$v = 1.713\times10^{7}$ m/s

$p = mv = (6.64\times10^{-27})(1.713\times10^{7}) = 1.14\times10^{-19}$ kgm/s

ii. Determine the kinetic energy of the recoiling thallium nucleus.

(e) Determine the total energy released during the decay of 1 mole of bismuth 212.

$E = mc^2$

$= 0.212(3\times10^{8})^2$

$= 1.91\times10^{16}$ J

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