

Q6 and Q7 concern ions emerging from a particle accelerator with total energy $12.5uc^2$ and momentum magnitude $3.5uc$, where u is a convenient unit of mass.

Q6 What is the mass of the ions? Select one item from the key. Pencil across *one* cell in row 6.

KEY for Q6

- | | |
|--|---------------|
| <input checked="" type="radio"/> A $12u$ | E $14u$ |
| B $12.5u$ | F $14.5u$ |
| C $13u$ | G $16u$ |
| D $13.5u$ | H None of A-G |

Q7 What is the speed of the ions? Select one item from the key. Pencil across *one* cell in row 7.

KEY for Q7

- | | |
|-----------|--|
| A $0.23c$ | <input checked="" type="radio"/> E $0.28c$ |
| B $0.25c$ | F $0.29c$ |
| C $0.26c$ | G $0.30c$ |
| D $0.27c$ | H None of A-G |

Q8 and Q9 concern a particle of mass $15m$ at rest in an inertial reference frame, which decays into another particle of mass $14m$ and a photon. [Hint: note that the photon is a massless particle, so for a photon travelling along the 1-axis $(p^0)^2 - (p^1)^2 = 0$.]

Q8 What is the energy of the emitted radiation? Select one item from the key. Pencil across *one* cell in row 8.

KEY for Q8

- | | |
|--|-----------------------|
| A $\frac{14}{15}mc^2$ | E $\frac{28}{27}mc^2$ |
| B $\frac{28}{29}mc^2$ | F $\frac{14}{13}mc^2$ |
| <input checked="" type="radio"/> C $\frac{29}{30}mc^2$ | G None of A-F |
| D mc^2 | |

Q9 Select from the key the item which is closest to the speed of the particle created in the decay. Pencil across *one* cell in row 9.

KEY for Q9

- | | |
|---|--------------------------------------|
| A Zero | E $3.0 \times 10^7 \text{ m s}^{-1}$ |
| B $1.5 \times 10^7 \text{ m s}^{-1}$ | F $3.5 \times 10^7 \text{ m s}^{-1}$ |
| <input checked="" type="radio"/> C $2.0 \times 10^7 \text{ m s}^{-1}$ | G $4.0 \times 10^7 \text{ m s}^{-1}$ |
| D $2.5 \times 10^7 \text{ m s}^{-1}$ | |

Q10 Which *one* of the following statements is false? Pencil across *one* cell in row 10.

KEY for Q10

- ☒ A The proper time between two events on a material particle's world-line is equal to the time separating those events as measured by a clock with the given world-line.
- B The proper time between two given events on a material particle's world-line is a Lorentz invariant quantity.
- ☒ C The proper time between two given events is independent of the material particle's world-line along which it is measured.
- D Given two different events \mathcal{E}_a and \mathcal{E}_b on a material particle's world-line, it is not possible in principle that the change in proper time in going from \mathcal{E}_a to \mathcal{E}_b along the given world-line is zero.
- E The proper time elapsed between any two events on a material particle's world-line is equal to or less than the corresponding time recorded between these two events by any inertial observer not moving with the particle.

Q11 Which two of the statements in the key are *true*? Pencil across *two* cells in row 11.

KEY for Q11

- ☒ A The principle of equivalence only applies to test-bodies that do not experience any non-gravitational forces.
- B The principle of equivalence asserts that in any region of spacetime it is impossible to distinguish the effects of uniform acceleration from those of gravitation by any kind of experiment.
- ☒ C The principle of equivalence asserts that in any local region of spacetime it is impossible to distinguish the effects of uniform acceleration from those of gravitation by any kind of experiment.
- D The principle of equivalence would be contradicted by the following observation: two identical particles, initially separated by a distance of 100 metres, are dropped simultaneously from the same altitude above the Earth; when they strike the Earth, they are separated by less than 100 metres.
- ☒ E The mathematical proof of the principle of equivalence is based on Newton's laws of motion and Newton's law of gravitation.
- ☒ F The principle of equivalence implies that within the framework of Newtonian mechanics, the gravitational mass of any body is proportional to the inertial mass of that body.

1) E 2) BC 3) CF 4) ABD 5) C 6) A
 7) E 8) C 9) C 10) C 11) CF 12) BDE
 13) BC 14) ACE 15) ACE 16) ACE 17) CD 18) D
 19) BEG