Mark scheme for Extension Worksheet – Option J, Worksheet 1

1 Because it has strangeness $S = +1$ and the antiparticle would have $S = -1$ and so different. [1]

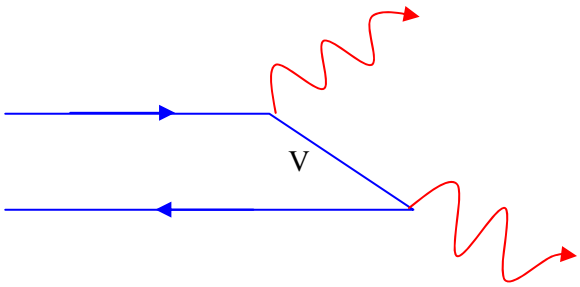
2 Two identical fermions cannot occupy the same quantum state. [1]

3 The Pauli principle applies to fermions; and photons are bosons. [2]

4 Use $\Delta E \Delta t \approx \frac{h}{4\pi} \Rightarrow \Delta E \approx \frac{h}{4\pi \Delta t}$; $\Delta E \approx \frac{6.63 \times 10^{-34}}{4\pi \times 10^{-12}} \approx 5 \times 10^{-23}$ J [2]

5 A particle which when it appears in an intermediate state in a Feynman diagram; violates energy and momentum conservation. [2]

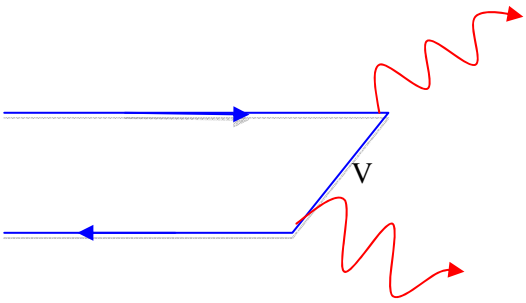
6 **a** See diagram. Blue line with right arrow is the u quark, blue line with left arrow is the u antiquark and the red bendy lines are photons.



[1]

b For this diagram the virtual particle V is a u quark. [1]

7 **a** The diagram can also be drawn as the following:

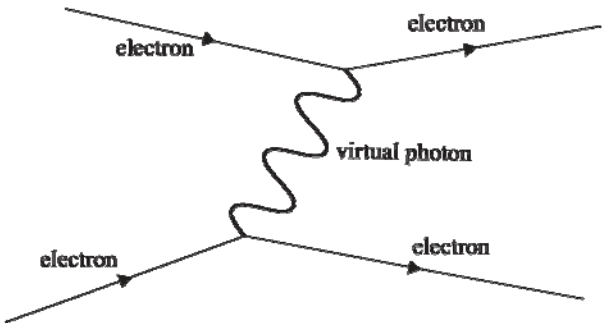


[2]

b For this diagram the virtual particle V is a u antiquark. [1]

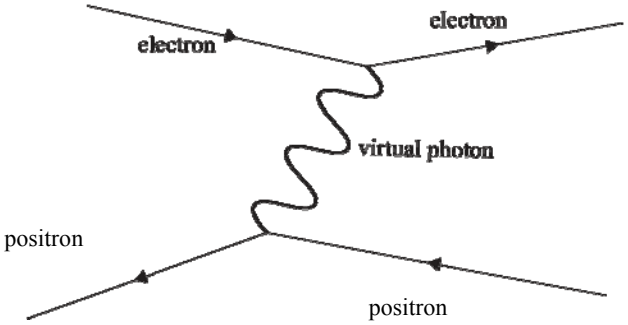
c In order to conserve muon lepton number. [1]

8 **a**



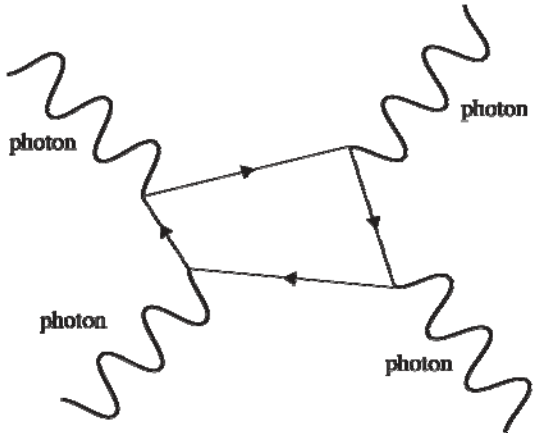
[1]

b



[1]

c



[1]

d Because there are 4 vertices in the Feynman diagram/each vertex contributes a factor of the electromagnetic interaction strength and this is less than one so many vertices result in less likely outcomes. [1]

9 Use the range formula $R \approx \frac{h}{4\pi mc} \Rightarrow m \approx \frac{h}{4\pi Rc}$; to get

$m \approx \frac{6.63\times10^{-34}}{4\pi\times10^{-18}\times3\times10^{8}} \approx 1.76\times10^{-25}$ kg ; hence

$m \approx \frac{1.76\times10^{-25}\times c^2}{1.6\times10^{-19}}$ eVc^{-2} $\approx 9.89\times10^{10}$ eVc^{-2} ≈ 98.9 GeVc^{-2} ≈ 100 GeVc^{-2} [3]

10 **a** The reaction violates strangeness conservation; and only the weak interaction can violate strangeness conservation. [2]

b No; because family lepton number must be conserved, it can be a muon neutrino only. [2]

11 Quarks; and gluons. [2]

12 The three u quarks are identical in every way, including the spin that has to be up; and this would violate the Pauli principle unless the three quarks could be differentiated in some way, for example with a new quantum number called colour. [2]

13 Confinement means that colour cannot be observed hence free quarks cannot be observed. [1]