School	*Candidate's Name (PLEASE PRINT)*
	Markscheme

WINCHESTER

COLLEGE

Election

Tuesday 7 May, 2019

Science

PHYSICS

THEORY SECTION

Recommended time: 20 minutes

Write all your answers in the spaces on this question paper

1 To prepare for extra-vehicular activity outside the International Space Station, astronauts train underwater in a pool on Earth called the neutral buoyancy laboratory. An astronaut, in her space-suit, has an average density of 915 kg/m^3, and a mass of 120 kg (including the suit).

(a) Show that the volume of the suit with the astronaut inside is 0.131 m^3, stating any formula you use.

$\text{Density} = \frac{\text{mass}}{\text{volume}} \Rightarrow \text{Volume} = \frac{\text{mass}}{\text{density}} = \frac{120\text{ kg}}{915\text{ kg/m}^3} \approx 0.131\text{ m}^3$ (3 s.f.) ✓

[1]

(b) In order to simulate some of the effects of 'weightlessness', the astronaut must be made *neutrally buoyant*. This means that her weight must be exactly balanced by the upthrust provided by the water when she is totally immersed. Archimedes' Principle tells us that the *upthrust is equal to the weight of the water displaced by a body*. The pool water has a density of 1.00 g/cm^3. How much mass must be added to the suit in order to make the astronaut neutrally buoyant? (Assume that the volume of the suit remains constant.)

Water Density = 1000 kg/m^3 ✓ Conversion, or correct conversion of volume to cm^3 and mass to g

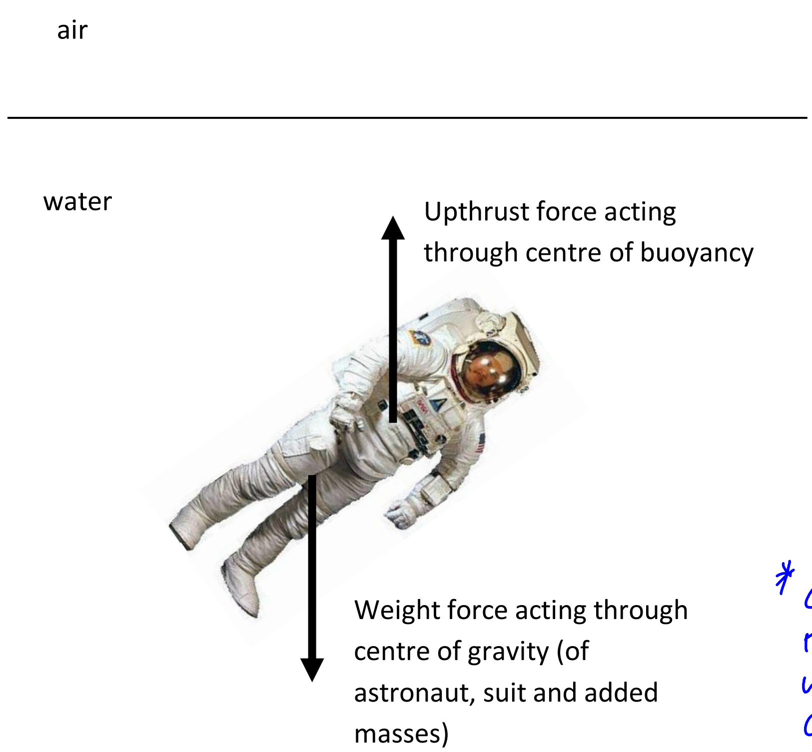
Mass = Density × volume

$= 1000\text{ kg/m}^3 \times 0.131\text{ m}^3$ ✓ $= 131\text{ kg}$

Mass must be 131 kg to be neutrally buoyant so [3]

added mass is $(131-120)\text{ kg} = 11\text{ kg}$ ✓

(c) After having the mass calculated in (b) added to the bottom of her boots, the astronaut is lowered so that she is totally submerged in the water with her body angled at 45° to the vertical. She is then released and finds that she rotates so that her feet point downwards. Use the diagram below to help you explain carefully why this happens, and what the support team would need to do in order to make sure that she remained stationary at 45° to the vertical when released.



* Credit given for the idea of adding weights to the centre of mass, even though this is not correct (1 mark)

The two forces do not act through the same point ✓. So there is an anticlockwise ✓ moment on her (until she is vertical and both forces act along the same line). To avoid this [3]

position the masses so that the centre of gravity coincides with the centre of buoyancy (or the) ✓

[more weights higher up the body until this is achieved*]

(d) The experience of working in the neutral buoyancy lab is not identical to that of working in space outside the International Space Station. Suggest one difference that the astronaut might notice.

Valid difference presented (✓), examples:

• In tank, will experience drag (but not in space)
(so something set in motion will stop quickly rather than continuing).

• The astronauts are not weightless within their suits, So for instance being orientated upside down could be uncomfortable [1]

2 This question is about the generation of electrical power.

(a) In a nuclear fission power plant, energy is released by splitting up nuclei of uranium-235 atoms. A neutron collides and combines with the uranium-235 nucleus. The nucleus becomes unstable and splits into two large parts, plus some neutrons: this process is called **fission**. Fission releases energy, which is initially carried as the kinetic energy of these two fragments, which is converted to heat energy. This is converted to electrical energy by the turbine and generator.

(i) An example of a nuclear reaction that can occur in the fission of uranium is shown below:

$$^{1}_{0}\text{n} + ^{235}_{92}\text{U} \rightarrow ^{137}_{52}\text{Te} + ^{97}_{40}\text{Zr} + 2\,^{1}_{0}\text{n}$$

The masses of the nuclei in this reaction are given below, in atomic mass units, *u*.

$u = 1.66 \times 10^{-27}$ kg.

	Mass in atomic mass units *u*
$^{1}_{0}\text{n}$	1.008
$^{235}_{92}\text{U}$	235.048
$^{137}_{52}\text{Te}$	136.918
$^{97}_{40}\text{Zr}$	96.906

Unlike chemical reactions, the mass can change during nuclear reactions. Show that the change in mass in this reaction is $0.216u$.

Calculation of at least the mass of one side → ✓

Mass of LHS = (1.008 + 235.048) u = 236.056

RHS = (136.918 + 96.906 + 2×1.008) = 235.840

Subtracting RHS from LHS → ✓

Difference LHS − RHS = 0.216 u [2]

(ii) If the mass decreases during a nuclear reaction, the mass deficit is converted to the kinetic energy of the products, using Einstein's famous equation

$$E = mc^2$$

Here $c = 3.00 \times 10^8$ m/s (the speed of light in vacuum). To use this equation, mass *m* must be in kilograms, and energy *E* in joules (J).

1. Calculate the energy released when 6.0×10^{23} uranium-235 nuclei undergo fission by the reaction in (i). This is approximately 235 g of uranium-235.

1/3 for use of $E = mc^2$ with 0.235 kg (but not if multiplied by 6×10^{23})

Mass decrease in kg per fission $= 0.216 \times 1.66 \times 10^{-27}$ kg $= 3.5856 \times 10^{-28}$ kg ✓

Mass decrease for 6.0×10^{23} reactions $= 2.15 \times 10^{-4}$ kg ✓ [3]

Energy release $= 2.15 \times 10^{-4}$ kg $\times (3.0 \times 10^{8}$ m/s$)^2 = 1.9 \times 10^{13}$ J ✓

2. How long will this number of atoms of uranium-235 keep a power plant with an electrical ~~energy~~ power output of 2 GW (2×10^9 joules per second) running. Assume that the power plant converts 33% of the energy released by fission into electrical energy (an efficiency of 33%).

Energy required from fission per second $= \frac{2 \times 10^9 \text{ J}}{0.33} = 6.06 \times 10^9$ J/s ✓

∴ runs for $\frac{1.9 \times 10^{13} \text{ J}}{6.06 \times 10^9 \text{ J/s}} = 3195$ s ✓

$= 3200$ s (2 s.f.) ✓ [3]

Allow ecf from 1.

2/3 for correct calculation but not taking account of efficiency.

1 mark awarded for some attempt to take efficiency into account even if rest of calculation incorrect.

[If using 0.235 kg as mass in (1), then the answer here is 3.5×10^6 seconds]

(iii) When a fission occurs, as well as producing the two large fragments, neutrons are released. These neutrons can go on to cause further fissions.

Explain carefully what happens to the reaction if, on average:

1. Fewer than one of these neutrons caused a further fission.

The reaction will slow down (✓) – less fissions per second as time goes on. Each reaction produces on average less than one further reaction (✓) [Reaction decays exponentially]

2. Exactly one of these neutrons caused a further fission.

The reaction continues at the same rate of energy production (✓) Each reaction causes exactly one further reaction so number of reactions per second constant. (✓)

3. More than one of these neutrons caused a further fission.

Credit given for sensible ideas in this section

The number of reactions per second increases ✓ out of control (exponential increase) ✓, because each reaction causes more than one further reaction, which each cause more than one further reaction ✓

MAX [5]

(b) Coal has a chemical energy density of 39.3 kilojoules per gram (1 kJ = 1000 J). We wish to produce 2.0×10^{9} joules of electrical energy per second from our power plant, which is 40% efficient at converting chemical energy in coal to electrical energy. How much coal must be supplied to the power plant per hour?

39.3 kJ/g = 39300 J/g ✓

$\frac{2.0\times10^{9}\ J/s}{39300\ J/g}$ = 50900 g/s ✓ at 100% efficiency

Only 40% efficient, so $\frac{50900\ g/s}{0.4}$ = 127 kg/s ✓

127 kg/s × 3600 s/hr = 458,000 kg/hr ✓ [4]

3/4 for calculation that doesn't take efficiency into account but is otherwise completely correct.

End of this paper