P8a The Solar System, Orbital Motion and Satellites

AQA 8463 · Calculator allowed · about 85 minutes

Total Marks

Name: ________________________________ Date: ____ / ____ / ______

Answer ALL questions. Show all your working.

Key words and equations: the Solar System, orbital motion and satellites (P8a)

Revision Library

The Solar System consists of the Sun (a star) and the objects that orbit it: eight planets, their natural satellites (moons), dwarf planets, asteroids and comets. A star forms from a nebula, a cloud of dust and gas, which is pulled together by gravity to form a protostar; once the core becomes hot and dense enough, nuclear fusion begins and a new star is born. For most of its life, a star sits on the main sequence, a long, stable period in which nuclear fusion of hydrogen into helium in its core balances the inward pull of gravity. A star with a similar mass to the Sun eventually becomes a red giant, then loses its outer layers to leave a white dwarf, which cools over a very long time into a black dwarf. A much more massive star becomes a red super giant, then explodes as a supernova, leaving behind either a neutron star or, if the remaining core is massive enough, a black hole; elements heavier than iron are only formed during a supernova explosion. An object moving in a circular orbit has a constantly changing direction of velocity, so it is always accelerating towards the centre of the orbit; this centripetal acceleration is caused by a centripetal force, which for an orbiting planet, moon or satellite is provided by gravitational attraction. For a stable orbit, an orbit with a larger radius requires a slower orbital speed, because gravitational force is weaker at greater distances. Equation used in this worksheet: orbital speed = (2 x pi x orbital radius) / time period (v = 2 x pi x r / T). A satellite is an object that orbits a larger object; a geostationary satellite orbits above the equator with a time period of 24 hours, staying above the same point on the Earth's surface, while a low polar orbit satellite orbits much closer to the Earth with a much shorter time period, passing over a different strip of the Earth's surface on each orbit.

1 The Solar System contains many different types of object, all orbiting the Sun (directly or indirectly).

(a) State what type of object the Sun is. **(1)**

(b) Name the objects that orbit the Sun directly, such as Earth and Jupiter. **(1)**

(c) Name the objects that orbit planets, such as the Moon orbiting the Earth. **(1)**

(d) Name two other types of smaller object found in the Solar System, in addition to planets and their moons. **(1)**

(Total for Question 1 is 4 marks)

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2 The Solar System, including the Sun and the planets, formed billions of years ago from a cloud of dust and gas.

(a) Name this initial cloud of dust and gas. **(1)**

(b) Name the force that causes the cloud to collapse and be pulled together. **(1)**

(c) Explain what happens to the material at the centre of the collapsing cloud, and what this eventually becomes. **(2)**

(Total for Question 2 is 4 marks)

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3 A star with a mass similar to the Sun passes through several stages during its life cycle.

(a) Put these four stages in the correct order, starting with the earliest: main sequence star, protostar, red giant, white dwarf. **(3)**

(b) State what a white dwarf eventually becomes, once it has cooled down completely and stopped glowing. **(1)**

(c) State the source of energy that keeps a star stable and glowing during the main sequence stage. **(1)**

(Total for Question 3 is 5 marks)

4 A star with a much greater mass than the Sun follows a different path after the main sequence.

(a) State the stage that a very massive star enters after leaving the main sequence, before it explodes. **(1)**

(b) Name the explosive event that ends the life of a red super giant. **(1)**

(c) State the two objects that a supernova can leave behind, and identify the factor that determines which one forms. **(3)**

(Total for Question 4 is 5 marks)

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5 Elements are created within the life cycle of a star.

(a) State the process, and the location within a star, by which elements up to iron are formed. **(2)**

(b) State when elements heavier than iron are formed. **(1)**

(Total for Question 5 is 3 marks)

6 A planet orbits the Sun in a stable, roughly circular orbit.

Figure (to be drawn): *A planet moving in a circular orbit around the Sun. Arrows are drawn at one point on the orbit: a velocity arrow tangent to the circle, and a force arrow pointing from the planet directly towards the Sun at the centre.*

(a) Name the force that keeps the planet in its orbit. **(1)**

(b) State the direction of this force, relative to the centre of the orbit. **(1)**

(c) The planet moves at a constant speed around its orbit. Explain why the planet is still accelerating, even though its speed does not change. **(2)**

(Total for Question 6 is 4 marks)

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7 For a stable circular orbit, the gravitational force provides exactly the centripetal force needed to keep an object moving in a circle at that radius.

(a) State what happens to the strength of the gravitational force between two objects as the distance between them increases. **(1)**

(b) Use this idea to explain why an object in a stable orbit at a large orbital radius has a lower orbital speed than an object in a stable orbit at a small orbital radius. **(3)**

(Total for Question 7 is 4 marks)

8 Satellites can be natural or artificial.

(a) Give one example of a natural satellite, other than the Moon. **(1)**

(b) State two uses of artificial satellites. **(2)**

(Total for Question 8 is 3 marks)

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9 A geostationary satellite is used for continuous communication with a fixed region on the Earth's surface.

(a) State the orbital period of a satellite in a geostationary orbit. **(1)**

(b) State the plane in which a geostationary satellite orbits, relative to the Earth. **(1)**

(c) Explain why a geostationary orbit is useful for a satellite television broadcasting company. **(1)**

(Total for Question 9 is 3 marks)

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10 A low polar orbit satellite is used to monitor the Earth's whole surface for weather forecasting.

(a) State one feature of the orbit that makes it a low polar orbit. **(1)**

(b) State how the orbital period of a low polar orbit satellite compares with that of a geostationary satellite. **(1)**

(c) Explain why a low polar orbit is useful for monitoring the whole of the Earth's surface over time. **(1)**

(Total for Question 10 is 3 marks)

11 Orbital speed, orbital radius and time period are linked by a single equation.

(a) Write down the equation linking orbital speed, orbital radius and time period. **(1)**

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(b) State the SI unit of orbital speed. **(1)**

(Total for Question 11 is 2 marks)

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12 A small satellite orbits the Earth at an orbital radius of 7.0 x 10^6 m, with a time period of 5800 s. Use the Physics Equations Sheet. Use the equation: orbital speed = (2 x π x orbital radius) / time period.

(a) Calculate the orbital speed of the satellite. **(3)**

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(Total for Question 12 is 3 marks)

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13 Higher Tier only. A satellite completes one orbit of the Earth in a time period of 7200 s, at an orbital speed of 6800 m/s. Use the Physics Equations Sheet. Use the equation: orbital speed = (2 x π x orbital radius) / time period.

(a) Rearrange the equation to make orbital radius the subject. **(1)**

(b) Calculate the orbital radius of the satellite. **(3)**

....

(Total for Question 13 is 4 marks)

14 Satellite P orbits at a smaller radius than satellite Q, and both are in stable circular orbits around the Earth.

(a) State which satellite, P or Q, has the greater orbital speed. **(1)**

(b) State which satellite, P or Q, has the longer time period for one orbit. **(1)**

(Total for Question 14 is 2 marks)

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15 The table shows the approximate orbital radius and orbital period for four types of satellite orbit.

Orbit type: Low Earth orbit, Medium Earth orbit, Geostationary orbit, Distant orbit

Orbital radius (x10^6 m): 6.8, 20, 42, 80

Orbital period (hours): 1.5, 12, 24, 63

(a) Describe the relationship shown by the data between orbital radius and orbital period. **(2)**

(b) Use the data to state which of the four orbit types would give a satellite the fastest orbital speed. **(1)**

(Total for Question 15 is 3 marks)

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16 A company is designing a new satellite to provide continuous, real-time internet coverage to a single fixed region of the United Kingdom. They are choosing between placing the satellite in a geostationary orbit or a low polar orbit. Evaluate which type of orbit would be more suitable for this purpose. In your answer, you should consider: the orbital period and altitude of each orbit type; how each orbit type would affect the satellite's position relative to the region being served; any other relevant advantages or disadvantages of each orbit.

(Total for Question 16 is 6 marks)

17 The Moon orbits the Earth, and the Earth orbits the Sun.

(a) State what provides the centripetal force that keeps the Moon in orbit around the Earth. **(1)**

(b) The Earth takes 1 year to orbit the Sun, and the Moon takes about 1 month to orbit the Earth. Using ideas about orbital radius, suggest why the Moon completes many more orbits of the Earth in a year than the Earth completes orbits of the Sun. **(2)**

(Total for Question 17 is 3 marks)

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18 Pluto is classified as a dwarf planet, not a full planet, even though it orbits the Sun. Comets and asteroids are also smaller objects found within the Solar System.

(a) State one similarity between a dwarf planet and a planet. **(1)**

(b) State one difference between a comet and an asteroid. **(2)**

(Total for Question 18 is 3 marks)

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19 A student incorrectly says that a star like the Sun produces energy by burning hydrogen gas, in the same way a fire burns fuel.

(a) State the correct process by which the Sun produces energy. **(1)**

(b) Explain why this process is different from ordinary burning (combustion). **(2)**

(Total for Question 19 is 3 marks)

20 The life cycle of a star depends on its mass.

(a) State one similarity between the life cycle of a star similar in mass to the Sun and a star with a much greater mass than the Sun. **(1)**

(b) State one key difference between the two life cycles, after the main sequence stage. **(2)**

(Total for Question 20 is 3 marks)

Mark scheme · P8a The Solar System, Orbital Motion and Satellites

Question 1

- (a) **B1** a star
- **(a) Answer: A star.**
- (b) **B1** planets
- **(b) Answer: Planets.**
- (c) **B1** (natural) satellites/moons
- **(c) Answer: Natural satellites (moons).**
- (d) **B1** any two of: dwarf planets; asteroids; comets
- **(d) Answer: Any two of: dwarf planets, asteroids, comets.**

Question 2

- (a) **B1** nebula
- **(a) Answer: Nebula.**
- (b) **B1** gravity (gravitational attraction)
- **(b) Answer: Gravity.**
- (c) **B1** the material at the centre becomes increasingly hot, dense and compressed as more material is pulled in by gravity
- (c) **B1** eventually this becomes hot and dense enough for nuclear fusion to begin, forming a new star, oe
- **(c) Answer: The material at the centre becomes hotter and denser until nuclear fusion begins, forming a new star.**

Question 3

- (a) **B1** protostar placed before main sequence star
- (a) **B1** main sequence star placed before red giant
- (a) **B1** red giant placed before white dwarf
- **(a) Answer: protostar, main sequence star, red giant, white dwarf**
- (b) **B1** black dwarf
- **(b) Answer: Black dwarf.**
- (c) **B1** nuclear fusion of hydrogen (into helium) in the star's core
- **(c) Answer: Nuclear fusion of hydrogen into helium.**

Question 4

- (a) **B1** red super giant (red supergiant)
- **(a) Answer: Red super giant.**
- (b) **B1** supernova
- **(b) Answer: Supernova.**
- (c) **B1** neutron star
- (c) **B1** black hole
- (c) **B1** depends on the mass of the remaining core/original star - only a sufficiently massive star leaves behind a black hole, oe
- **(c) Answer: A neutron star or a black hole; a black hole only forms from a sufficiently massive remaining core.**

Question 5

- (a) **B1** nuclear fusion
- (a) **B1** in the core of the star
- **(a) Answer: Nuclear fusion, in the core of the star.**
- (b) **B1** during a supernova explosion
- **(b) Answer: During a supernova explosion.**

Question 6

- (a) **B1** gravitational force (of attraction between the Sun and the planet)
- **(a) Answer: Gravitational force.**
- (b) **B1** towards the centre of the orbit (towards the Sun)
- **(b) Answer: Towards the centre of the orbit.**
- (c) **B1** velocity depends on both speed and direction, and although the speed is constant, the direction of the planet's motion is continuously changing
- (c) **B1** a change in velocity means the planet is accelerating, with the acceleration directed towards the centre of the orbit, oe
- **(c) Answer: Its direction keeps changing, so velocity changes, so it is accelerating towards the centre of the orbit.**

Question 7

- (a) **B1** the gravitational force decreases (gets weaker)
- **(a) Answer: It decreases.**
- (b) **B1** at a larger orbital radius, the gravitational force is weaker
- (b) **B1** a weaker force provides a smaller centripetal force
- (b) **B1** a smaller centripetal force is needed to keep an object moving in a circle at a lower speed, so the orbital speed needed for a stable orbit is lower at a larger radius, oe
- **(b) Answer: Weaker gravity at a larger radius provides less centripetal force, which is only enough to hold an object in a stable orbit if it moves more slowly.**

Question 8

- (a) **B1** any moon of another planet, e.g. a moon of Jupiter or Saturn
- **(a) Answer: E.g. a moon of Jupiter.**
- (b) **B1** first correct use, e.g. communications (television/phone signals); weather monitoring/forecasting; satellite navigation (GPS-type systems); Earth observation/environmental monitoring; scientific research/astronomy
- (b) **B1** second correct use, different from the first (from the same list)
- **(b) Answer: Any two of: communications, weather monitoring, satellite navigation, Earth observation, scientific research.**

Question 9

- (a) **B1** 24 hours (1 day)
- **(a) Answer: 24 hours.**
- (b) **B1** above the equator (in the plane of the equator)
- **(b) Answer: Above the equator.**
- (c) **B1** the satellite stays above the same point on the Earth's surface at all times, since its orbital period matches the Earth's rotation, so a satellite dish on the ground can stay pointed in a fixed direction, oe
- **(c) Answer: It stays above the same point, so ground dishes never need to move.**

Question 10

- (a) **B1** it orbits at a low altitude, close to the Earth's surface, passing near/over the North and South poles on each orbit, oe
- **(a) Answer: It orbits close to the Earth, passing near the poles.**
- (b) **B1** it is much shorter (much less than 24 hours)
- **(b) Answer: It is much shorter.**
- (c) **B1** the satellite passes over a different strip of the Earth's surface on each orbit, as the Earth rotates beneath it, so given enough time it can image/monitor the whole surface, oe
- **(c) Answer: It passes over a different strip of the Earth each orbit as the Earth turns, eventually covering the whole surface.**

Question 11

- (a) **B1** orbital speed = (2 x π x orbital radius) / time period
- **(a) Answer: orbital speed = (2 x π x orbital radius) / time period**
- (b) **B1** metres per second, m/s

Question 12

- (a) **M1** substitution: $v = (2 \times \pi \times 7.0 \times 10^6) / 5800$, oe
- (a) **M1** correct evaluation of the numerator: $2 \times \pi \times 7.0 \times 10^6 = 4.398 \times 10^7$
- (a) **A1** v = 7580 m/s (3 s.f.), cao (accept awrt 7580 m/s)
- **(a) Answer: v = 7580 m/s**

Question 13

- (a) **B1** orbital radius = (orbital speed x time period) / (2 x π)
- **(a) Answer: r = (v x T) / (2 x π)**
- (b) **M1** substitution: $r = (6800 \times 7200) / (2 \times \pi)$, oe
- (b) **M1** correct evaluation of the numerator: $6800 \times 7200 = 4.896 \times 10^7$
- (b) **A1** $r = 7.79 \times 10^6$ m (3 s.f.), cao (accept awrt 7.79×10^6 m)
- **(b) Answer: $r = 7.79 \times 10^6$ m**

Question 14

- (a) **B1** satellite P
- **(a) Answer: Satellite P.**
- (b) **B1** satellite Q
- **(b) Answer: Satellite Q.**

Question 15

- (a) **B1** as orbital radius increases, orbital period increases
- (a) **B1** the increase is not directly proportional - the period increases more steeply than the radius (e.g. radius increases by a factor of about 12 from Low Earth orbit to Distant orbit, but the period increases by a factor of 42), oe
- **(a) Answer: Orbital period increases as orbital radius increases, but not in direct proportion; period increases more steeply than radius.**
- (b) **B1** Low Earth orbit - it has both the smallest orbital radius and the shortest orbital period, oe
- **(b) Answer: Low Earth orbit.**

Question 16

- **Level 0** (0): No relevant content.
- **Level 1** (1-2): Isolated statement(s) are made about one orbit type, with little or no evaluation.
- **Level 2** (3-4): Relevant points are made about both orbit types, with some comparison, but the conclusion may not be clearly justified.
- **Level 3** (5-6): A detailed, well-reasoned evaluation of both orbit types is given, leading to a clearly justified conclusion, with correct scientific vocabulary throughout.
- **Indicative content:**
  - A geostationary orbit has a time period of 24 hours and stays above the same point on the Earth's equator/surface at all times.
  - This means a satellite dish on the ground could stay pointed in one fixed direction, useful for continuous coverage of a single fixed region.
  - A geostationary orbit is at a very high altitude, so the signal travels a long distance, which can introduce a noticeable delay in real-time communication.
  - A low polar orbit satellite orbits at a much lower altitude, closer to the Earth, giving a shorter signal delay.
  - However, a low polar orbit satellite moves quickly relative to the ground and only passes over the UK for a short time on each orbit, so continuous coverage of a single fixed region would need a large constellation of many satellites working together.
  - A single geostationary satellite can provide constant coverage of a fixed region, whereas a single low orbit satellite cannot.
  - A valid conclusion: for continuous single-region coverage with minimal ground equipment, a geostationary orbit is more suitable overall, though a low-orbit constellation could offer a lower signal delay if enough satellites are used, oe (accept a different, well-justified conclusion).

Question 17

- (a) **B1** the gravitational force between the Earth and the Moon
- **(a) Answer: Gravitational force between the Earth and the Moon.**
- (b) **B1** the Moon's orbital radius around the Earth is much smaller than the Earth's orbital radius around the Sun
- (b) **B1** a smaller orbital radius corresponds to a much shorter time period, so the Moon completes far more orbits in the same amount of time, oe
- **(b) Answer: The Moon's orbit has a much smaller radius, giving a much shorter time period, so it completes far more orbits per year.**

Question 18

- (a) **B1** e.g. both orbit the Sun / both are roughly spherical due to their own gravity
- **(a) Answer: E.g. both orbit the Sun.**
- (b) **B1** a comet is made mostly of ice, dust and rock, and develops a visible tail as it nears the Sun
- (b) **B1** an asteroid is made mostly of rock and/or metal, and does not typically develop a tail, oe (accept the converse ordering)
- **(b) Answer: A comet is icy and develops a tail near the Sun; an asteroid is rocky/metallic and does not.**

Question 19

- (a) **B1** nuclear fusion (of hydrogen nuclei to form helium)
- **(a) Answer: Nuclear fusion.**
- (b) **B1** nuclear fusion involves the nuclei of atoms joining together, releasing energy from within the nucleus, not a chemical reaction with oxygen
- (b) **B1** ordinary burning/combustion is a chemical reaction between a fuel and oxygen, releasing much less energy per kilogram of fuel than nuclear fusion, oe
- **(b) Answer: Fusion joins atomic nuclei together, releasing far more energy than the chemical reaction of burning with oxygen.**

Question 20

- (a) **B1** e.g. both begin as a nebula and pass through a main sequence stage powered by nuclear fusion, oe
- **(a) Answer: E.g. both pass through a main sequence stage.**
- (b) **B1** a Sun-sized star ends as a white dwarf (then a black dwarf), while a massive star explodes as a supernova
- (b) **B1** a massive star can leave behind a neutron star or black hole, which a Sun-sized star's life cycle never produces, oe
- **(b) Answer: A Sun-sized star ends as a white/black dwarf; a massive star explodes as a supernova, leaving a neutron star or black hole.**