School	Candidate's Name (PLEASE PRINT)

WINCHESTER
COLLEGE

Election

2023

Science

PHYSICS

THEORY SECTION

Recommended time: 25 minutes

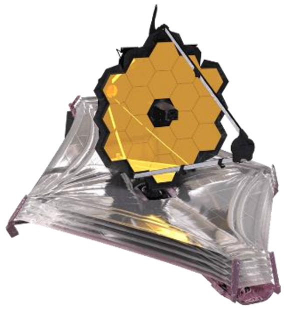
Write all your answers in the spaces on this question paper

An electronic calculator is required

MAXIMUM MARK = 25

1 The *James Webb Space Telescope* (JWST) was launched on Christmas Day 2021 and has been operational since the summer of 2022.

(a) JWST collects *infra-red light* via a mirror comprising eighteen hexagonal segments of gold-plated beryllium.



[JWST spacecraft model 3 - James Webb Space Telescope - Wikipedia]

The mirror can be considered to be a circle of *diameter* 6.5 m. Show that the *area* of the JWST mirror is about seven times larger than the mirror of the Hubble Space Telescope, which has an *area* of 4.5 m^2.

The area A of a circle is $A = \pi r^2$ where r is the radius.

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(b) JWST will execute a small circular 'halo' orbit about the L2 ('Lagrange Point') in the Earth-Sun system. The L2 point *itself* orbits about the Sun with the *same period as the Earth*, which means the Sun is always partially blocked ('eclipsed') by the Earth, helping to cool JWST.

The L2 point is $R = 1.5 \times 10^8$ km (150 000 000 km) from the Sun, and one year is $T = 365 \times 24 \times 3600$ seconds. Calculate the *orbital speed* of JWST about the Sun in km/s.

The circumference of a circle of radius R is $2\pi R$.

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2 (a) JWST is a very delicate instrument, and contains a large five-layer sunshield. Each layer is a film made from plastic, aluminium and silicon. Each is about as thin as a human hair.

An object made of this material travelling several km/s would not last for long in the atmosphere, but scientists expect the JWST to be useable for the next 20 years. Explain this.

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(b) Engineers at NASA communicate with JWST via a *microwave link* between antennas on Earth and those mounted on the spacecraft. Microwaves are *electromagnetic waves*, which travel at the speed of light in a vacuum.

The L2 point is 1.5×10^9 m from Earth, and the speed of light is $c = 3.0 \times 10^8$ m/s. Calculate the time it takes a signal to travel from JWST to Earth.

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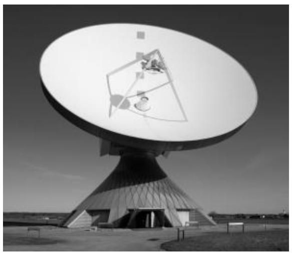

A satellite communication antenna.
https://en.wikipedia.org/wiki/Microwave_transmission

3 (a) Unlike Hubble, which is sensitive to *visible light*, JWST will observe the Cosmos in the *Infra-Red* part of the **Electromagnetic Spectrum.** The longest *wavelength* it can receive is $\lambda = 28.3$ μm where 1 μm = 10^{-6} m.

All hot bodies radiate electromagnetic waves, and the peak of the *radiation spectrum** from a body of temperature T (in Kelvin, K) will have wavelength given by the equation: $\lambda = \frac{2{,}900\ \mu\text{m}}{T}$.
Calculate the temperature T (in K) which corresponds to an Infra-Red wavelength of 28.3 μm.

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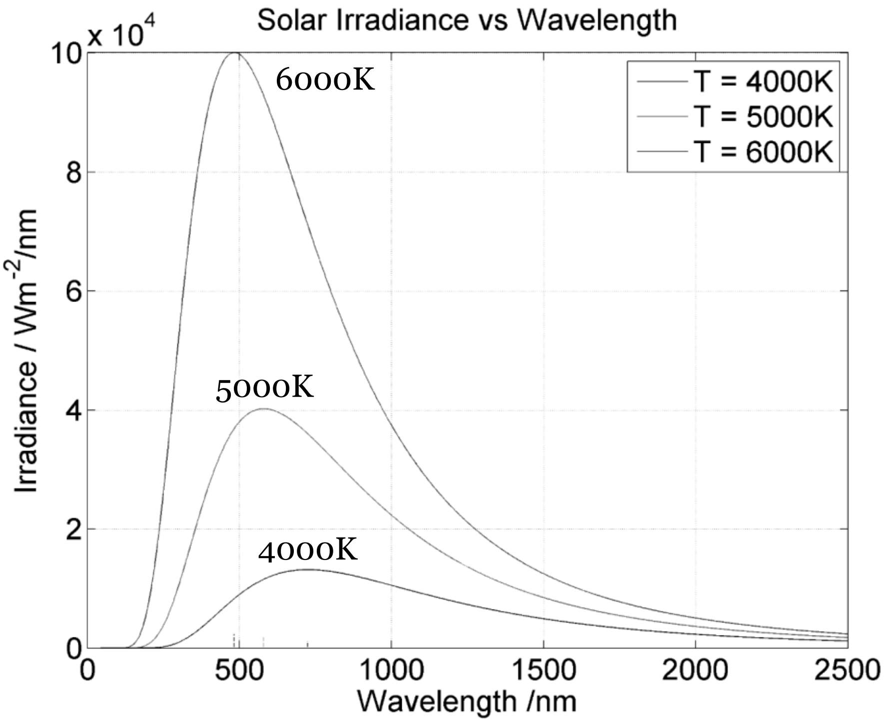
*i.e. a graph of *irradiance*, which is the power per unit area, per wavelength, plotted against *wavelength.* The graph below illustrates irradiance vs wavelength for three stars at temperatures 4,000 K, 5,000 K and 6,000 K.



(b) The Sun has a surface temperature of about T = 5,800 K. Use the formula in (a) to calculate the associated peak wavelength λ in μm.

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(c) The figure below shows the electromagnetic spectrum. Identify the region in the electromagnetic spectrum indicated by your answer to (b).

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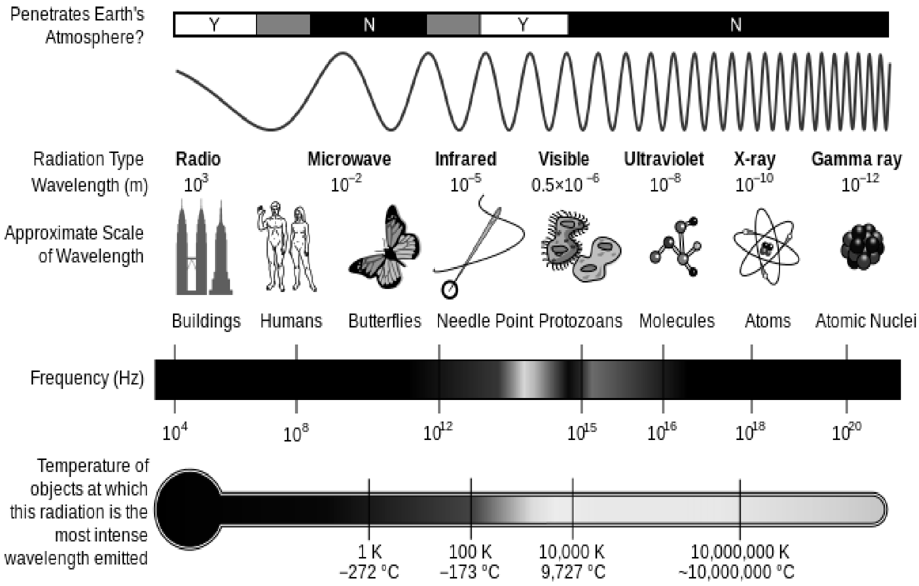

The Electromagnetic Spectrum.
https://commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_edit.svg

4 (a) The total amount of *radiation power* (in joules per second or J/s) from a star is called its *luminosity*. Luminosity L can be calculated by multiplying the *surface area* of a star, $4\pi r^2$, (where r is its radius) by σT^4, where T is the surface temperature in K, and the constant $\sigma = 5.67 \times 10^{-8}\,\mathrm{Js^{-1}m^{-2}K^{-4}}$.

Show that the luminosity of the Sun (of radius 700 000 000 m) is about $L = 4 \times 10^{26}$ J/s.

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(b) Sunlight on the solar panels of a satellite in a near-Earth orbit can receive a maximum power of $\Phi =$ 1,400 J/s *for every square metre* of solar panel.

The power *per unit area* Φ at distance r from the Sun is the *luminosity L* divided by the *area of a sphere of radius r.*

Show using algebra that: $r = \sqrt{\dfrac{L}{4\pi\Phi}}$

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(c) Hence determine the distance r between the Earth and the Sun. Express your answer in **standard form**, in metres.

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End of this paper

[Total for this paper: 25]