Are You Ready for S818?

Are you ready for S818 Space Science?

The purpose of this document is to allow you assess for yourself whether your academic background suitably prepares you for the Master's level module S818 Space Science. This is a core module in the MSc in Space Science and Technology.

For entry to S818 we expect students to have a degree (or equivalent qualification) in physics, astronomy, geosciences, chemistry, engineering or mathematics. Note that we do not assume previous study in space science or astronomy.

S818 is a broad ranging module which covers a diverse range of scientific topics. However, in order to understand the engineering constraints that apply to space missions and the environment in which spacecraft operate, it is necessary to have an understanding of key concepts from physics and a certain level of proficiency in mathematics.

The purpose of this document is to allow you to **diagnose your preparedness** for S818. It is split into two sections. You should work through the questions in both sections. It is important to appreciate that this diagnostic material provides **an indicator of how prepared you are for S818**, but it is **not** an exhaustive check list of every topic and technique that you may need.

It is strongly recommended that you set aside sufficient time to work through all of this test in one sitting. You may need up to an hour to work through all of the questions, but this will be time well-spent if it helps you to judge whether you are adequately prepared for S818.

Diagnostic questions

There are ten questions, each of which has a maximum score of 10 marks.

Mathematical skills

Question 1

This question tests your understanding of trigonometric functions.

Find the values of x at which the following functions have a maximum value. Express your answers in radians.

(i) $\sin x$

(ii) $\sin\left(x + \frac{\pi}{4}\right)$

(iii) $-\cos(x)$

(iv) $\sin(4x)$

(v) $\sin x \cos x$

Question 2

This question tests your conceptual understanding of vectors.

If $\boldsymbol{a}$ and $\boldsymbol{b}$ are two (non-null) vectors, what do the following equations imply about the magnitude and direction of these two vectors?

(i) $\boldsymbol{a} - \boldsymbol{b} = \boldsymbol{0}$

(ii) $\boldsymbol{a} - 2\boldsymbol{b} = \boldsymbol{0}$

(iii) $\boldsymbol{a} + \boldsymbol{b} = \boldsymbol{0}$

(iv) $\boldsymbol{a} \cdot \boldsymbol{b} = 0$

(v) $\boldsymbol{a} \times \boldsymbol{b} = \boldsymbol{0}$

Question 3

This questions tests your knowledge of vector algebra and your ability to calculate quantities in vector equations.

If vectors $\boldsymbol{p}$ and $\boldsymbol{q}$ can be written in terms of rectangular Cartesian components (with unit vectors $\boldsymbol{i}, \boldsymbol{j}, \boldsymbol{k}$ in the *x*-, *y*- and *z*- directions respectively)

$$\boldsymbol{p} = 2\boldsymbol{i} + 5\boldsymbol{j} + 3\boldsymbol{k}$$

$$\boldsymbol{q} = -\boldsymbol{i} + 3\boldsymbol{j} + 2\boldsymbol{k}$$

Calculate

(i) $\boldsymbol{p} + \boldsymbol{q}$

(ii) $\boldsymbol{p} - 2\boldsymbol{q}$

(iii) $|\boldsymbol{p}|$

(iv) $\boldsymbol{p} \cdot \boldsymbol{q}$

(v) $\boldsymbol{p} \times \boldsymbol{q}$

Question 4

This question tests your knowledge of differential calculus.

In the following equations, a and b are constants, and E is a function of the variable t. Find expressions for dx/dt in terms of a, b, E and dE/dt

(i) $x = aE + b$

(ii) $x = aE^2 + bE$

(iii) $x = a \cos E$

(iv) $x = a \exp(-bE)$

(v) $x = aE + btE$

Question 5

This question tests your knowledge of integral calculus.
Evaluate the following definite integrals in terms of x_1 and A (which are constants):

(i) $\int_{x=0}^{x_1} Ax \, \mathrm{d}x$

(ii) $\int_{x=x_1}^{\infty} \frac{A}{x^2} \mathrm{d}x$

(iii) $\int_{x=x_1}^{2x_1} \frac{A}{x} \mathrm{d}x$

(iv) $\int_{0}^{\infty} A\mathrm{e}^{-x} \mathrm{d}x$

(v) $\int_{x=0}^{\infty} \mathrm{e}^{-x/A} \mathrm{d}x$

Concepts in physics

Question 6

This question tests your knowledge of physical units.

Fill in the missing blanks in the table below.

Name / symbol of unit	**Physical quantity measured**	**SI unit?**
meters (m)		Y
gram (g)		
kilometers (km)		
year		
hertz (Hz)	Frequency	
electron-volt (eV)		
	Energy	Y
Watt-hour		
	Angular speed	Y
revolutions minute^{-1}		
	Force	Y
	Potential difference	Y
	Power	Y
	Torque	Y

Question 7

This question tests your conceptual understanding of dynamics.

During the Apollo 14 mission, astronaut Alan Shepard famously hit a golf ball on the surface of the Moon.

Think about such a shot, and decide which of the following statements are true. Then explain your reasoning.

Assume that there is no difference in height between the launch point and the location where the ball impacts the surface. Also assume that the lunar environment is a perfect vacuum.

Statement	**True / False**	**Explanation**
The acceleration of the ball is constant from the moment the ball leaves the face of the golf club to the moment it hits the lunar surface.		
The path of the ball would follow a sinusoidal curve.		
The speed of the ball on impact with the lunar surface would be the same as the speed that it left the face of the golf club.		
The velocity of the ball on impact with the lunar surface would be the same as the velocity that it left the face of the golf club.		
The spin rate of the ball remains constant from the moment it leaves the face of the club until it impacts the lunar surface.		

Question 8

This question tests your knowledge of particles.

Fill in the blanks in this table.

Name	**Electric charge**	**(Approximate) Mass / Mass of proton**	**Stable against decay?**
Electron	–e		
Proton			Yes
Neutron			
Alpha particle			

Question 9

This question tests your knowledge of electromagnetic (e.m.) radiation.

(a) Fill in the right hand column of this table with the in the order of increasing wavelength (1 for shortest wavelength, 2 for next shortest etc)

Type of electromagnetic radiation	**Order of increasing wavelength**
Far-infrared	
Radio	
Microwave	
Visible light	
Gamma-rays	
Hard x-rays	
Terahertz radiation	
Extreme ultraviolet	
Near-infrared	
Soft x-rays	

(b) Calculate the frequency of e.m. radiation (travelling through a vacuum) which has a wavelength of 30 cm. Express your answer in the most appropriate units for an engineering application.

Question 10

This question is about blackbody radiation

(a) Give the expression for the power emitted by an object radiating as a perfect black-body, defining all symbols that appear in this expression.

(b) If the temperature of such a body changes from 200 °C to 400 °C, what is the ratio of the emitted power at these two temperatures?

Self-assessment

Mark your responses according to the scoring set out in the solutions section and record your scores below:

Mathematical skills

Question	1	2	3	4	5	Subtotal

Physics concepts

Question	6	7	8	9	10	Subtotal

Total score	

If you have **scored less than 60 overall**, then we recommend that you **do not study S818** at this point. You should consider studying stand-alone undergraduate physics or mathematics modules in order to be adequately prepared for S818.

If you have scored between 60 and 80, then you are likely to struggle to some degree with the physics and mathematical content of S818. You should carefully consider whether S818 is an appropriate module for you to study. If you have time, carrying out preparatory work (see below) before the module starts may however be sufficient to prepare you for the module.

If you achieved a score of over 80, it is likely that your academic background is suitable for S818. In the following section we provide some suggestions of other preparatory work you could usefully conduct before the module starts.

Preparatory Work

If you scored between 60 and 80 then you **are strongly recommended to do some preparatory study** to enhance your skills and knowledge prior to starting S818. A resource that you can use for this is the (electronic) text called “An Introduction to Astrophysics and Cosmology” by Andrew Norton and which can be obtained as detailed below. You should aim to work through Chapters 1, 4 and 5 prior to starting S818.

If you scored over 80 you should revise any areas of weakness identified in the test. If there are no such areas, you could then choose either to revise some astronomy or geology (if you do not have a background in these areas). Alternatively you could also usefully start developing your coding skills.

If you have little astronomical background, then you could usefully work through Chapters 2 and 3 of “An Introduction to Astrophysics and Cosmology” by Andrew Norton (see below). This will help you to better understand the space environment and prepare you for some of the scientific topics that you will cover in the module.

The module covers science topics related to the surfaces of the Moon and Mars and this requires some knowledge of geological processes and terminology. If you have little knowledge of geology, a good starting point would be the section entitled “Earth Sciences: reading the rocks”, which forms the first half of the free online module “Practising science: Reading the rocks and ecology”.

If you do have the relevant background in astronomy and geology, and are otherwise well-prepared, you can usefully spend time starting the free online module called “Learn to code for data analysis” (see below). As part of S818 you will need to complete the first six sections of this module.

Resources

“An Introduction to Astrophysics and Cosmology” by Andrew Norton

http://www.open.ac.uk/science/physical-science/sites/www.open.ac.uk.science.physical-science/files/files/book0_2016.pdf

“Learn to code for data analysis” a free online course available (from early 2018) through OpenLearn

https://www.open.edu/openlearn/science-maths-technology/learn-code-data-analysis/content-section-overview-0?active-tab=description-tab

“Practising science: Reading the rocks and ecology” is a free online course available through OpenLearn:

https://www.open.edu/openlearn/science-maths-technology/geology/practising-science-reading-the-rocks-and-ecology/content-section-0?active-tab=description-tab

Other OpenLearn resources that may be useful for developing your knowledge of geology are:

Sedimentary processes: http://www.open.edu/openlearn/science-maths-technology/across-the-sciences/exploring-sedimentary-processes

Clay and the possibility of life on Mars: http://www.open.edu/openlearn/science-maths-technology/astronomy/what-does-clay-tell-us-about-the-possibility-life-on-mars

Answers to self-assessment questions

Mathematical skills

Question 1

(i) $\sin x$
has a maximum when
$x = (\pi/2) + 2\pi n$
where *n* is any integer.

(ii) $\sin\left(x + \frac{\pi}{4}\right)$
has a maximum when
$x + \pi/4 = (\pi/2) + 2\pi n$
where *n* is any integer. So,
$x = (\pi/4) + 2\pi n$

(iii) $-\cos(x)$
has a maximum when
$x = \pi + 2\pi n$
where *n* is any integer.

(iv) $\sin(4x)$
has a maximum when
$4x = (\pi/2) + 2\pi n$
where *n* is any integer. So,
$x = (\pi/8) + (\pi n/2)$

(v) $\sin x \cos x$
Noting that $\sin 2x = 2 \sin x \cos x$, then
$\sin x \cos x = \frac{1}{2} \sin 2x$
This has a maximum when
$2x = (\pi/2) + 2\pi n$
where *n* is any integer. So,
$x = (\pi/4) + \pi n$

Scoring: 2 mark for each fully correct answer (1 mark only if only one maximum given).

Maximum score: 10

Question 2

(i) $\boldsymbol{a} - \boldsymbol{b} = \boldsymbol{0}$
The vectors $\boldsymbol{a}$ and $\boldsymbol{b}$ are equal (i.e. they are equal in magnitude and oriented in the same direction).

(ii) $\boldsymbol{a} - 2\boldsymbol{b} = \boldsymbol{0}$
The vectors $\boldsymbol{a}$ and $\boldsymbol{b}$ are oriented in the same direction, but the magnitude of $\boldsymbol{a}$ is twice that of $\boldsymbol{b}$.

(iii) $\boldsymbol{a} + \boldsymbol{b} = \boldsymbol{0}$
The vector $\boldsymbol{a}$ is oriented in the opposite direction to $\boldsymbol{b}$, but their magnitudes are equal.

(iv) $\boldsymbol{a} \cdot \boldsymbol{b} = 0$
The angle between the directions of $\boldsymbol{a}$ and $\boldsymbol{b}$ is $\pi/2$ radians (i.e. the vectors are orthogonal).

(v) $\boldsymbol{a} \times \boldsymbol{b} = \boldsymbol{0}$
The directions of $\boldsymbol{a}$ and $\boldsymbol{b}$ are parallel.

Scoring: 2 mark for each fully correct answer. 1 mark for a partially correct statement. Maximum score: 10.

Question 3

(i) $\boldsymbol{p} + \boldsymbol{q} = 2\boldsymbol{i} + 5\boldsymbol{j} + 3\boldsymbol{k} - \boldsymbol{i} + 3\boldsymbol{j} + 2\boldsymbol{k} = \boldsymbol{i} + 8\boldsymbol{j} + 5\boldsymbol{k}$

(ii) $\boldsymbol{p} - 2\boldsymbol{q} = 2\boldsymbol{i} + 5\boldsymbol{j} + 3\boldsymbol{k} + 2\boldsymbol{i} - 6\boldsymbol{j} - 4\boldsymbol{k} = 4\boldsymbol{i} - \boldsymbol{j} - \boldsymbol{k}$

(iii) $|\boldsymbol{p}| = (2^2 + 5^2 + 3^2)^{1/2} = (38)^{1/2} = 6.164$

(iv) $\boldsymbol{p} \cdot \boldsymbol{q} = 2 \times (-1) + 5 \times 3 + 3 \times 2 = 19$

(v) $\boldsymbol{p} \times \boldsymbol{q} = \begin{vmatrix} \boldsymbol{i} & \boldsymbol{j} & \boldsymbol{k} \\ 2 & 5 & 3 \\ -1 & 3 & 2 \end{vmatrix} = (10-9)\boldsymbol{i} + (-3-4)\boldsymbol{j} + \big(6-(-5)\big)\boldsymbol{k} = \boldsymbol{i} - 7\boldsymbol{j} + 11\,\boldsymbol{k}$

Note that you may be more accustomed to expressing vectors as ordered sets of numbers, such as e.g. $\boldsymbol{p} = (2.0, 5.0, 3.0)$. The set book for S818 uses basis unit vector notation as in this question and you should feel confident in using either representation.

Scoring: 2 marks for each correct answer. Maximum score: 10.

Question 4

(i) $x = aE + b$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = a\frac{\mathrm{d}E}{\mathrm{d}t}$$

(ii) $x = aE^2 + bE$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = 2aE\frac{\mathrm{d}E}{\mathrm{d}t} + b\frac{\mathrm{d}E}{\mathrm{d}t} = (2aE + b)\frac{\mathrm{d}E}{\mathrm{d}t}$$

(iii) $x = a\cos E$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = a\sin E\frac{\mathrm{d}E}{\mathrm{d}t}$$

(iv) $x = a\exp(-bE)$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = -ab\exp(-bE)\frac{\mathrm{d}E}{\mathrm{d}t}$$

(v) $x = aE + btE$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = a\frac{\mathrm{d}E}{\mathrm{d}t} + b\left(E + t\frac{\mathrm{d}E}{\mathrm{d}t}\right)$$

$$\frac{\mathrm{d}x}{\mathrm{d}t} = bE + (a+t)\frac{\mathrm{d}E}{\mathrm{d}t}$$

Scoring: 2 marks for each correct answer. Maximum score 10.

Question 5

(i) $\int_{x=0}^{x_1} Ax\,\mathrm{d}x = A\left[\frac{x^2}{2}\right]_0^{x_1} = \frac{A}{2}{x_1}^2$

(ii) $\int_{x=x_1}^{\infty} \frac{A}{x^2}\,\mathrm{d}x = A\left[\frac{-1}{x}\right]_{x_1}^{\infty} = A\left[0 - \left(\frac{-1}{x_1}\right)\right] = \frac{A}{x_1}$

(iii) $\int_{x=x_1}^{2x_1} \frac{A}{x}\,\mathrm{d}x = A[\ln x]_{x_1}^{2x_1} = A[\ln 2x_1 - \ln x_1] = A\ln 2 \approx 0.6931A$

(iv) $\int_{x=0}^{\infty} A\mathrm{e}^{-x}\mathrm{d}x = A[-\mathrm{e}^{-x}]_0^{\infty} = A[0-(-1)] = A$

(v) $\int_{x=0}^{\infty} \mathrm{e}^{-x/A}\mathrm{d}x = \left[-A\mathrm{e}^{-x/A}\right]_0^{\infty} = [0-(-A)] = A$

Scoring – 2 marks per correct answer. 1 mark for partial answers. Maximum score 10.

Concepts in physics

Question 6

Name / symbol of unit	Physical quantity measured	SI unit?
meters (m)	Length	Y
gram (g)	Mass	N
kilometers (km)	Length	N
year	Time	N
hertz (Hz)	Frequency	Y
electron-volt (eV)	Energy	N
joule (J)	Energy	Y
Watt-hour	Energy	N
rad s^{-1}	Angular speed	Y
revolutions $minute^{-1}$	Angular speed	N
newton (N)	Force	Y
volt (V)	Potential difference	Y
watt (W)	Power	Y
N m	Torque	Y

Scoring: 1/2 mark for each correct item in the table. Maximum score 10

Question 7

The completed table is shown below

Statement	True / False	Explanation
The acceleration of the ball is constant from the moment the ball leaves the face of the golf club to the moment it hits the lunar surface.	True	After the ball is struck the only force acting on it is that due to lunar gravity. This force is constant (in magnitude and direction) over the trajectory of the ball, so the acceleration is also constant.
The path of the ball would follow a sinusoidal curve.	False	The path of a projectile in a uniform gravitational field, in the absence of any other forces, would be a parabola rather than a sinusoid.
The speed of the ball on impact with the lunar surface would be the same as the speed that it left the face of the golf club.	True	Since the launch and impact points are at the same height and there are no other energy losses, the kinetic energy on impact will be the same as the kinetic energy on launch. Hence the speed of the ball is the same at launch and impact points.
The velocity of the ball on impact with the lunar surface would be the same as the velocity that it left the face of the golf club.	False	While the speed of the ball will be the same at impact as on launch, the direction of travel is different at these two times. Hence the velocity of the ball at these two times is different.
The spin rate of the ball remains constant from the moment it leaves the face of the club until it impacts the lunar surface.	True	The spin rate will only change if a torque acts on the ball. In the absence of air resistance there is no such torque and the spin rate remains constant.

Scoring: 1 mark for each correct True/False statement. 1 mark for each explanation (award 1 for partial explanations). Maximum score for question 10.

Question 8

The completed table is shown below

Name	Electric charge	(Approximate) Mass / Mass of proton	Stable against decay?
Electron	–e	~ 1/2000	Yes
Proton	+e	1	Yes
Neutron	0	1	No
Alpha particle	+2e	4	Yes

Scoring: 1 mark per correct item in the table. Maximum score for question:10

Question 9

(a) The completed table is shown below

Type of electromagnetic radiation	**Order of increasing wavelength**
Far-infrared	7
Radio	10
Microwave	9
Visible light	5
Gamma-rays	1
Hard x-rays	2
Terahertz radiation	8
Extreme ultraviolet	4
Near-infrared	6
Soft x-rays	3

Scoring: Starting from the maximum of 5 marks, deduct 1 mark for every item that is not in the correct sequence (down to a minimum of 0).

(b) The frequency v and wavelength λ of e.m. radiation are related by $c = v\lambda$ where c is the speed of light in a vacuum (approximately 3.0×10^8 m s^{-1}).

$$v = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \text{m s}^{-1}}{0.30 \text{ m}} = 1.0 \times 10^9 \text{Hz}$$

So the frequency of e.m. radiation with a wavelength of 30 cm is 1.0 GHz (or 1000 MHz).

Scoring: 2 marks for equation for frequency, 2 marks for numerical working and 1 mark for expressing answer in GHz (or MHz).

Maximum score for question: 10

Question 10

(a) The power (P) emitted from an object radiating as a perfect black-body is given by

$$P = A\sigma T^4$$

where A is the surface area of the body, T is its (absolute) temperature and σ is the Stefan-Boltzmann constant.

(the Stefan-Boltzmann constant has a value of 5.67×10^{-8} W m^{-2} K^{-4} in SI units, but you are not expected to be able to remember this.)

Scoring: 2 marks for the equation and 1 mark for correct definition of each term on the right hand side.

(b) The ratio of the radiant power emitted at T_2 to that emitted at T_1 is

$$\frac{P_2}{P_1} = \frac{A\sigma T_2^4}{A\sigma T_1^4} = \frac{T_2^4}{T_1^4}$$

The Stefan-Boltzmann law is stated in terms of absolute temperatures, so it is necessary to convert the temperatures as follows:

$$T_1 = 200℃ \equiv (200 + 273)\ \mathrm{K} = 473\ \mathrm{K}$$

$$T_2 = 400℃ \equiv (400 + 273)\ \mathrm{K} = 673\ \mathrm{K}$$

So the ratio is

$$\frac{P_2}{P_1} = \left(\frac{673\ \mathrm{K}}{473\ \mathrm{K}}\right)^4 = (1.423)^4 = 4.10$$

The ratio of power emitted at 400 °C to that emitted at 200 °C is 4.1.

Scoring: 2 marks for the expression for the ratio of power, 2 mark for converting to absolute temperatures and 1 mark for obtaining correct numerical answer.

Maximum score for question: 10