# Preparation for the British Astronomy & Astrophysics Olympiad Paper

Oct 2020

This paper is a longer paper, up to three hours long. It is about solving a small number of problems in some depth rather than many one-step questions. It is designed to be challenging and so it should not be disquieting to find that there are questions which you struggle to do. The topics covered are the ones that are to be found in the various physics A level syllabi, but any one syllabus will certainly not have all of these. In some cases, the material will be in an optional module. However, the material not in the syllabus is relatively easy to pick up oneself. There are a number of good textbooks which cover the majority of the topics, and a few common ones are listed at the end. A few of the American College textbooks for the first year of university cover the ground quite well, having a more mathematical approach than an A level text. They also have plenty of examples to assist and many worked out examples in the text itself. But there are many and you would have to inspect them first to see if they covered the topics. Physics books approach topics from a physicist's point of view and an astronomy book which covers the topics has an advantage.

The following topics are those that can be asked about, but it is not limited to these topics. Material that the student would not be expected to know is included in the question, and is part of the skill of answering such problem questions; taking in new information and being able to use it in context.

Proofs are not asked for although simple derivations could be required to show an understanding of the concepts, quantities and relations.

This list is not an exhaustive list and items may be asked about that are not included here. Information will be given in the question to permit the student to be able to progress. Practice on past questions will give a clearer indication of the level and content.

(i) Mathematical skills

Fluency with the mathematical skills of A level mathematics. Further Maths is not expected.

Basic calculus; differentiation and integration of polynomials and exponentials. Any other integrals will be given

Chain rule, product rule, quotient rule.

(ii) Kepler's Laws

A detailed knowledge of ellipses and other conics is not required, with the material covered in an A level maths course being more than sufficient.

The Cartesian equation for the ellipse and recognising a parametric form; geometry of the parabola and hyperbola.

The sum of the lengths from each focus to a point on the ellipse are constant. Eccentricity of an ellipse, semi-major and semi-minor axes, area of an ellipse

$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

Ability to use simple trigonometry for the plane of orbit tilted with respect to the line of sight.

Kepler's 2nd Law, of equal areas in equal times. Area of arc length is $A = \frac{1}{2} r^2 d\theta$

Kepler's 3rd Law for ellipses in the form of the square of the period of orbit proportional to the cube of the semi-major axis. Realise that the semi-major axis is numerically equal to arithmetic average of the furthest distance and the nearest distance from the central mass during orbit.

(iii) Newton's Law of Gravitation

An inverse square law of force. Gauss's Law – no field inside a spherical shell. Fields and forces, potential and potential energy for spherical masses. Neutral points, equipotentials and field lines. Escape velocity. Centre of mass. Moments.

(iv) Simple aspects of elliptical orbits

Orbits of comets, satellites, planets, etc.

(v) Tidal effects; why two tides a day, time lag of moon and its effect, relative effect of Sun and Moon.

(vi) Magnitudes, luminosity, intensity, shape of black body spectrum and temperature of body.

$$L = \varepsilon \sigma A T^4$$

The relative brightness of two objects whose intensities (brightness) measured from Earth in units of power per unit area (W m$^{-2}$) are $I_1$ and $I_{\mathrm{ref}}$, will have magnitudes $m_1$ and $m_{\mathrm{ref}}$ related by (Pogson's equation). Relative magnitudes, absolute magnitudes (at 10 pc)

$$m_1 - m_{\mathrm{ref}} = -2.5 \log_{10}\left(\frac{I_1}{I_{\mathrm{ref}}}\right) \quad \text{or} \quad \frac{I_1}{I_{\mathrm{ref}}} = 10^{-0.4(m_1 - m_{\mathrm{ref}})}$$

(vii) Inverse square law of forces/radiation

From a point source, intensity $\propto \frac{1}{r^2}$

Luminosity $L = 4\pi I r^2$

(viii) Hubble's Law

Objects generally beyond our Milky Way galaxy, which are not gravitationally bound to us ($> 10$ Mpc), are observed to be receding from our viewpoint. The expanding universe is simply described by a linear expansion of the form $v = Hr$ where the Hubble constant $H = 70\ \mathrm{km\ s^{-1} Mpc^{-1}}$

Conversion to $H = 2.3 \times 10^{-18}\ \mathrm{s^{-1}}$

Use of $z$ (redshift velocity), which is the recessional velocity that would produce the same redshift if it were caused by a linear Doppler effect (which it is not). It is an effect due to the expansion of space.

$$Z = \frac{\lambda_0}{\lambda_e} - 1 = \frac{v}{c}$$

(ix) Schwarzschild radius

Know that the radius used for a Black Hole (the Schwarzschild radius) is $R_S = \frac{2GM}{c^2}$

(x) Doppler effect

The approximation, $\frac{\Delta f}{f} = \frac{v}{c}$ is used for $v \ll v$

$$\frac{\Delta\lambda}{\lambda} = -\frac{v}{c}$$

$$f_o = f_e\left(1 \pm \frac{v}{c}\right)$$

(The relativistic formula will not be required).

(xi) Wien's Law

For a black body radiation spectrum emitted by a hot body, the peak intensity of the spectrum occurs at a wavelength $\lambda_{max}$ and is related to the temperature, $T$, of the body by

$$T\lambda_{max} = \text{constant}$$

(xii) Telescopes - optics, magnification, Rayleigh criterion

Newtonian reflecting and simple refracting telescopes. Simple principle of their construction and **normal** adjustment. Principle of equatorial telescope mount. Construction of radio telescope. Resolving power of a circular telescope aperture, Rayleigh criterion, $\theta_{res} = 1.22\frac{\lambda}{D}$

(xiii) The Solar system

Some knowledge of the planets, their nature (outer gas giants, inner rocky planets) and their order from the Sun.

(xiv) Parallax

The parsec; $1\ \text{pc} = 3.09 \times 10^{16}\ \text{m}$

(xv) Eclipses, transits

Why lunar eclipses do not occur each month; solar eclipse (total, partial, annular); significance of the transit of Venus as a historic event; transits of extrasolar planets. Eclipses of binary stars. Light curves.

(xvi) Observational astronomy

Some knowledge of the night sky, constellations, paths of the Sun, Moon and planets. Terminology, including ecliptic, celestial equator, RA, declination, latitude, longitude, great circle, meridian.

Notation of the objects in the Solar System: e.g. solar mass, radius, $M_\odot$, $R_\odot$ , etc.

# Books

For further BAAO preparation, recommendations are asterisked. Nos 4 (Fleisch) and 8 (Kutner) might be the most suitable.

1. ** *Fundamental Astronomy 5th ed., H Karttunen et al., Springer (2007).*

(this seems to available as an online download, although I think that is a copyright issue)

A technical book, which would need to be used very selectively.

2. *** *Schaum's Outlines – Astronomy, Stacey E Palin, McGraw Hill (2002)*

A very good source of questions, not too technical and clearly explained. Inexpensive and easily obtained.

3. * *Astronomy: Principles and Practice 4th ed., AE Roy and D Clarke, IoP Publishing (2003)*

A good technical book, readable, but to be used selectively for topics and for reference. The level of mathematics is generally at A level, but it does go further and it is for the long term rather than quick coverage of BAAO topics.

4. ****** *A Students Guide to the Mathematics of Astronomy, Daniel Fleisch and Julia Kregenow, CUP (2013)*

Not expensive, covers the ground in a manner that would be recognised by A level students. A small book by astronomy standards, but designed to introduce students to the technical aspects of the subject without overwhelming them. Very focused on calculations and at just the right level for the BAAO. Strictly designed to cover the calculational aspects of the subject rather than the observational. Highly recommended.

5. **** *The Paradoxical Universe, V. V. Ivanov, A. V. Krivov, P. A. Denissenkov, St Petersberg University*

Download from https://www.scribd.com/doc/250358664/The-Paradoxical-Universe

This is an online book of questions and some solutions in the Russian style. It can be a bit mind-boggling at times, and some of the questions are not very clear, as this is probably a machine translated version.

6. * *Advanced Physics 2nd ed., Steve Adams and Jonathan Allday, OUP (2013)*

A well thought of A level physics text, which will therefore be at the right level. A bit low on stretching mathematics, but good if you already have a copy. It has short chapters, so it will not have too much on the astronomy alone, but it is a quick lead in to each topic. Very expensive and so should not be bought just for a bit of astronomy preparation. Not very many question at the right level for this particular preparation.

7. *Physics : Algebra and Trigonometry 3rd ed., Eugene Hecht , Brooks Cole (2003)*

One of the very good American college textbooks on physics. A good range of questions, but very much a physics book. Has most of the topics above, but by no means all, and certainly from the physicist's perspective rather than any astronomical applications. Better to use an astronomy text, but some of the college texts now have astronomy in them. Expensive.

8. ********* *Astronomy: a Physical Perspective 2nd ed., Marc L Kutner, CUP (2003)*

An excellent text with lots of examples and questions, mathematically at the right level, interesting to read but not too long in getting down to the calculations.

9. ***** *Introductory Astronomy and Astrophysics 4th ed., Stephen A. Gregory and Michael Zeilik, Saunders College Publishing ( 1997)*

A little dated in B&W but a highly recommended book as a beginning undergraduate text. However, the Olympiad is at that level for a very narrow range of topics, and so this would be suitable as long as one is not too daunted by the coverage.

10. *Universe 10th ed., Roger Freedman , Robert Geller, William J. Kaufmann, W. H. Freeman (2015)*

A good introductory text, but probably not quite what is wanted for a fast preparatory route for solving problems in astronomy & astrophysics. There are many well written texts at this level, e.g. *The Cosmos 4th ed., Jay M Pasachoff and Alex Filippenko, CUP*, which are immensely informative, well written and printed and certainly give one an excellent background, but they would not be the most suitable preparation for the BAAO papers at this early stage.

11. ****** *Essentials of Astronomy 2nd ed., Lloyd Motz and Anneta Duveen, Columbia University Press (1977) o/p.*

A very good old fashioned book (i.e. you will be transported back to the 1960s with the layout) which brings in the maths at the right level at every opportunity. No time wasting on beautiful pictures of the universe, or descriptions of our place in the universe. If you have done an A level course in the physics, this will join on to the end quite nicely. Long out of print but available second hand.

12. *An Introduction to Modern Astrophysics 2nd ed., BW Carroll and DA Ostlie, Pearson (2014)*

Definitely the next level. This is an excellent book, but parts are what you might aspire to if you make the team for the IOAA.

13. *The Physical Universe: An Introduction to Astronomy, Frank H Shu, University Science Books (1982) o/p.*

A little dated now, but for some aspects of the subject it provides an excellent introduction to first year university. Hard facts and not a colour image in sight.  For the next stage, however, rather than for BAAO preparation. When you make it onto the team…..