Department for Education

Astronomy

GCSE subject content

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Contents

The content for GCSE astronomy

Introduction

1. The GCSE subject content sets out the knowledge, understanding and skills common to all specifications in GCSE astronomy.

2. They provide the framework within which the awarding organisation creates the detail of the specification.

Aims and objectives

3. GCSE specifications in astronomy should enable students to:

- understand the structures of the Earth, Moon and Sun; and how their interactions produce many of the astronomical cycles and phenomena of our natural world
- understand the Earth's place within the Solar System and the universe; and the forces which have shaped both our own and other planetary systems
- understand the forces governing the life-cycles of stars; and demonstrate a knowledge of how stars appear in the night sky
- understand how astronomers discovered the Earth's position within our galaxy and the Universe; and understand current theories for the evolution of the Universe
- understand the challenges inherent in making observations in astronomy; and the ways in which technology has aimed to overcome them
- apply observational, enquiry and problem-solving skills, through the use of information from aided and unaided astronomical observations; and use these skills to evaluate observations and methodologies

4. GCSE specifications in astronomy should give students the opportunity to:

- develop an informed interest in current astronomical investigations, discoveries and space exploration
- acquire knowledge and understanding of astronomy theory and practice, and the skills needed to investigate a wide range of astronomical contexts
- understand that the study and practice of astronomy are interdependent and iterative activities, and appreciate the links between astronomy and other branches of science
- develop an awareness that the study and practice of astronomy are subject to limitations by e.g. economic, technical, ethical and cultural influences
- progress to further and higher education courses in the fields of astronomy or physics

Subject content

5. There are two main sections below, which demonstrate how specifications in astronomy should enable students to show their understanding of the concepts and principles of astronomy.

6. In the first section, the main ways in which working scientifically should be developed and assessed are set out and explained. Specifications must encourage the development of knowledge and understanding in astronomy through opportunities for working scientifically.

7. The second section sets out the key ideas and subject content for astronomy. This content section also provides some context for the depth of treatment for both teaching and learning. Specifications should be designed to set out the level of understanding which students are expected to acquire.

8. The content sections also set out the mathematical skills required for astronomy. In order to develop their skills, knowledge and understanding in astronomy, students need to have been taught, and demonstrate competence, to select and apply the appropriate areas of mathematics relevant to the subject, as set out under each topic. The mathematical skills are also listed in appendix 1.

Working scientifically

9. This section explains, with both general and subject-specific examples, the main ways in which working scientifically must be developed and assessed.

Development of scientific thinking

- understand how scientific methods and theories develop over time
- use a variety of models – such as representational, spatial, descriptive, computational and mathematical – to solve problems, make predictions and develop scientific explanations, and understand familiar and unfamiliar facts and observations
- appreciate the power and limitations of theories in astronomy
- explain how every day and technological applications of science are used in astronomy; evaluate associated personal, social and economic implications; and make decisions based on the evaluation of evidence and arguments
- recognise the importance of peer review of results and of communicating results to a range of audiences

Observational skills and strategies

- use scientific theories and explanations to develop hypotheses
- plan observations to test hypotheses, check data or explore phenomena
- apply knowledge of a range of techniques, instruments and apparatus to select those appropriate to the observation

- understand how to carry out observations appropriately with due regard to the correct manipulation of equipment, the accuracy of measurements, and health and safety considerations
- understand how to make and record observations and measurements using a range of apparatus and methods
- evaluate methods and suggest possible improvements and further iterations

Analysis and evaluation

- apply the cycle of collecting, presenting and analysing data, including:

  - presenting observations and other data using appropriate methods
  - translating data from one form to another
  - carrying out and representing mathematical and statistical analyses
  - representing distributions of results and making estimations of uncertainty
  - interpreting observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions
  - presenting reasoned explanations including relating observations and data to hypotheses
  - being objective, evaluating data in terms of accuracy, precision, repeatability and reproducibility, and identifying potential sources of random and systematic error
  - communicating the scientific rationale for observations, methods used, findings, and reasoned conclusions through paper-based and electronic reports, and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms

Scientific vocabulary, quantities, units, symbols and nomenclature

- use scientific vocabulary, terminology and definitions
- recognise the importance of scientific quantities and understand how they are determined
- use SI units and related derived units (e.g. kg, km, ly, pc, AU)
- use prefixes and powers of ten for orders of magnitude (e.g. tera, giga, mega, kilo, centi, milli, micro and nano)
- interconvert units
- use an appropriate number of significant figures in calculation

Knowledge and understanding

10. Specifications in GCSE astronomy require students to understand the various bodies which make up the Solar System, the Milky Way galaxy and our Universe, their interactions, and the processes which govern their formation and development.

11. Specifications must require students to develop an understanding of the scientific processes involved in the discovery of these bodies and processes.

The Earth, Moon and Sun

12. Specifications in GCSE astronomy must require students to understand the key physical properties of each of these three bodies, and the importance of astronomical cycles created by them, including night and day, seasons, tides, lunar phases and eclipses, and their role in our timekeeping and calendar systems.

13. Specifications must require students to understand the following:

The Earth

- shape, mean diameter and major internal divisions of the Earth including crust, mantle, inner and outer core
- major divisions of Earth's surface including equator, tropics, Arctic and Antarctic circles, and prime meridian
- latitude and longitude co-ordinate system
- Earth's atmosphere, including sky colour and light pollution
- Earth's magnetosphere, including Van Allen belts and aurorae

The Moon

- shape, mean diameter and major internal divisions of the Moon including a comparison with the internal structure of the Earth
- principal naked-eye surface formations, their structure and origin, including craters, maria, terra, mountains and valleys
- lunar orbit including synchronous nature, rotational and revolution periods, and near and far sides
- theories of lunar formation including giant impact hypothesis

The Sun

- principal features and dimensions of the Sun including core, photosphere, chromosphere and corona including their structures and temperatures
- solar energy production including nuclear fusion
- the solar cycle
- sunspots including structure, origin and evolution
- solar appearance in different regions of the electromagnetic (EM) spectrum
- safe observation of the Sun including projection and H-alpha filters
- solar wind and its principal effects in the Solar System including effects on comets and space weather

Earth-Moon-Sun interactions

- scale of Earth-Moon-Sun system including the work of Eratosthenes and Aristarchus in determining relative distances and diameters
- lunar phases and their cycle
- libration – effects on lunar disc, as viewed from Earth, and causes
- eclipses including lunar and solar, partial and annular
- tides – effects of Moon and Sun in producing high, low, spring and neap tides

Time

- Earth's rotation and apparent diurnal motion of sky including sidereal and synodic day
- Moon's rotation and revolution including sidereal and synodic month
- annual variation in sunrise and sunset including the year
- equinoxes and solstices
- apparent and mean Sun (Apparent Solar Time (AST), Local Mean Time (LMT) and Greenwich Mean Time (GMT))
- the equation of time
- shadow stick data and determination of local noon
- measurement of longitude by astronomical (lunar distance) and horological (Harrison's marine chronometer) methods
- sundials

Use of mathematics

- substitute numerical values into algebraic equations using appropriate physical quantities e.g. in reproducing Eratosthenes' calculations or when using the Equation of Time (3c)
- use angular measures in degrees (5a)
- recognise and use expressions in standard form e.g. when considering the actual size and relative scale of the Earth-Moon-Sun system (1b)
- use ratios to determine the relative sizes of the Moon, Earth and Sun (1c)
- use ideas of latitude and longitude (5d)
- translate information between graphical and numerical forms e.g. when working with data on shadow lengths and directions from shadow sticks and sundials or on tides (4a)
- change the subject of an equation e.g. the equation of time (3b)
- solve simple algebraic equations (3d)
- use specialist units such as the au (2c)
- use degrees, minutes and seconds of arc (5b)
- convert between hours, minutes and seconds, and decimal fractions of hours (5b)

Planetary systems

14. Specifications in GCSE astronomy must require students to understand how developments in science led to the idea that stars, like the Sun, are at the centre of planetary systems, as well as the major physical processes which govern the formation and orbits of bodies such as planets. Specifications must also require students to consider the search for intelligent life elsewhere in the universe.

15. Specifications must require students to understand the following:

Formation processes

- the role of gravity in creating stable orbital paths
- the tidal effect of gravity in creating rings systems and asteroids
- the balance between tidal and elastic forces – qualitative explanation of the Roche limit
- the balance between gravitational and thermal factors in the creation of planetary atmospheres
- theories for the formation of gas giant planets
- theories for the current position and orientation of planets in our Solar System

Our Solar System

- bodies in our Solar System including planets, dwarf planets and small solar system objects (asteroids, comets and meteoroids)
- structure and orbits of comets
- origin and structure of meteoroids, meteors and meteorites
- principal characteristics of the planets including relative size, mass, surface temperature, atmosphere, satellite and ring systems
- scale and size of the Solar System
- Kuiper belt and Oort cloud and heliosphere

Finding our place in the Solar System

- transition from geocentric to heliocentric view
- importance of detailed observation of solar and lunar cycles by ancient civilisations in agricultural, religious and calendar systems
- evidence for highly detailed observations of solar and lunar cycles by ancient civilisations in the astronomical alignments of their monuments around the world
- appearance of Solar System from Earth including ecliptic plane and zodiac, retrograde motion of planets, conjunction, opposition, elongation, transit and occultation
- Greek epicycle system
- observational work of Brahe and Galileo
- mathematical modelling of Copernicus and Kepler
- Kepler’s laws of planetary motion

- elliptical orbits including aphelion and perihelion, apogee and perigee
- Newton's gravitational explanation for elliptical orbits
- Halley's use of transits of Venus to determine the size of the astronomical unit and thus the size of the Solar System

Planetary systems around other stars

- exoplanets
- methods for discovering exoplanets
- extra-terrestrial life and requirements for life in other solar systems
- Goldilocks zone
- theories of origins of water on Earth
- Drake Equation and its implication for the existence of life elsewhere in the galaxy
- benefits and dangers of discovering extra-terrestrial life including SETI (search for extra-terrestial intelligence)

Use of mathematics

- use specialist units: au, ly and pc when considering the size of solar systems and the distances to other stars (2c)
- understand the principles of calculations involving light years (2d)
- use ratios and inverse square relationships when using Newton's law of universal gravitation (1c)
- solve algebraic equations such as Kepler's third law of planetary motion (3d)
- substitute numerical values into algebraic equations using appropriate physical quantities e.g. in reproducing Eratosthenes' calculations (3c)
- translate information between graphical and numeric form (4a)
- plot two variables from experimental or other data (4b)
- solve simple problems using numerical probability (2e)
- use a calculator to determine squares, square roots and cubes of positive numbers when using Kepler's third law of planetary motion (1e)

Stars

16. Specifications in GCSE astronomy must require students to explore the fascination with the stars in the night sky that has existed since ancient times, leading to names for stars and constellations. Specifications must cover using the stars to find directions and positions on the Earth; the basics of the celestial sphere system for modelling their diurnal motion; and the true nature of the stars and their radiation, along with their varied evolution.

17. Specifications must require students to understand the following:

Observing the night sky

- appearance of stars and double stars
- constellations, asterisms and pointers
- open clusters, globular clusters and nebulae
- the Messier and New General Catalogues
- Bayer system for naming brightest stars within constellations
- differing constellation and star names amongst different cultures
- use of star chart, planisphere, computer program or app to identify objects observed in the night sky
- visibility, seeing conditions and light pollution
- naked eye techniques such as dark adjustment and averted vision

The celestial sphere

- celestial sphere, poles and equator
- ecliptic and first points of Aries and Libra
- right ascension and declination co-ordinate system
- observer's horizon including cardinal points, zenith and meridian
- altitude and azimuth
- apparent rotation of celestial sphere including rising, setting and culmination, and circumpolar stars
- star trails and Earth's sidereal period
- determination of latitude using pole star
- gradual precession of Earth's orbit/equinoxes and its use in archaeoastronomy

Physical properties of stars

- stellar magnitude system
- apparent and absolute magnitudes, and distance-modulus formula
- stellar spectra and spectral lines
- spectral class
- stellar temperatures and colours
- the Hertzsprung-Russell diagram, including main sequence, red and blue giant, white dwarf and supergiant regions
- stellar distance measurement methods including heliocentric parallax and the parsec, the inverse square law for radiation, the Hertzsprung-Russell diagram and Cepheid variables
- variable stars and light curves
- stellar groupings including binary stars and clusters

Evolution of stars

- gravity – radiation pressure balance within stars
- evolution of stars as a result of changes in this balance, including qualitative treatment of electron and neutron pressure

- principal stages of stellar evolution – nebula, main sequence star, red giant, white dwarf, black dwarf, planetary nebula, supernova, neutron star and black hole
- Chandrasekhar limit

Use of mathematics

- change the subject of an equation (3b)
- substitute numerical values into algebraic equations using appropriate physical quantities (3c)
- solve simple algebraic equations (3d)
- translate information between graphical and numeric form such as on the Hertzsprung-Russell diagram (4a)
- plot two variables from experimental or other data such as when using the right ascension (RA) and declination (Dec) coordinate system or when plotting a stellar light curve or Hertzsprung-Russell diagram (4b)
- use angular measure in degrees when using the declination system (5a)
- use specialist units such as ly, pc and kpc when considering the distances to stars (2c)
- understand the principles of calculations involving light years (2d)
- use ratios and inverse square relationships such as when considering the decreasing apparent brightness of stars with increasing distance (1c)
- use degrees, minutes and seconds of arc when working with the celestial and horizon coordinate systems (5b)
- use the concept of subtended angle when working with the celestial and horizon coordinate systems (5c)
- use concepts of 3D motion, rotation and coordinates on a sphere when working with the celestial and horizon coordinate systems (5d)
- understand and use logarithms (base 10) in equations and as scales and graphs such as when using the distance modulus formula (1d)

Galaxies and cosmology

18. Specifications in GCSE astronomy must require students to understand galaxies and cosmology, which centres around the discovery that the Solar System is part of the Milky Way galaxy and that this galaxy is one of billions comprising the Universe. Specifications must require students to understand the complex observations involved in this discovery and the competing theories proposed to explain them.

19. Specifications must require students to understand the following:

Finding our place in the Universe

- Milky Way galaxy including appearance from Earth, spiral structure and diameter
- our position within Milky Way galaxy
- determination of spiral arms by 21cm radio observations

- the Local Group including structure and scale

Galaxies

- Hubble classification system for galaxies
- evolution of galaxies
- active galaxies including types and emissions
- links to supermassive black holes

Cosmology

- observation of red-shifted light from distant galaxies
- discovery of expanding universe
- Hubble's law and the Hubble constant
- estimation of age and size of universe
- explanations for the expansion of the universe including steady state and big bang theories
- observation of quasi-stellar (QSOs)/quasars
- observation of cosmic microwave background radiation (CMBR)
- detailed measurements of CMBR (Planck)
- models of future development of universe
- possible nature and significance of dark matter and dark energy

Use of mathematics

- change the subject of an equation such as Hubble's law (3b)
- substitute numerical values into algebraic equations, such as Hubble's law, using appropriate physical quantities (3c)
- solve simple algebraic equations such as Hubble's law (3d)
- translate information between graphical and numeric form such as when working with data on the distances and recessional speeds of distant galaxies (4a)
- plot two variables from experimental or other data such as when working with data on the distances and recessional speeds of distant galaxies (4b)
- determine the slope of a linear graph such as when determining Hubble's constant (4c)
- use angular measure in degrees (5a)
- use specialist units such as ly, pc and kpc when working with distances to objects within our galaxy and (Mpc) when considering the distances to other galaxies (2c)
- understand the principles of calculations involving light years (2d)
- use ratios and inverse relationships such as when using Hubble's law (1c)

Observational technology

20. Specifications in GCSE astronomy must require students to consider the particular challenges posed by the observational, rather than experimental, nature of

astronomy. Specifications must require students to appreciate that the astronomer's constant need to minimise the effect of, rather than control, variables and their lack of a traditional laboratory environment lies at the heart of the design of their observational programmes and, hence, an iterative approach to observation is necessary in order to compensate for previously unknown or unpredictable factors.

21. Specifications must require students to understand that the constant drive to improve the accuracy, detail and range of observations has provided a context for the invention of the telescope, the development of orbital platforms to the manned exploration of the Moon, and probes to the outer reaches of our Solar System.

22. Specifications must require students to understand the following:

Ground-based observation

- optical telescopes including refracting (Galilean and Keplerian) and reflecting (Newtonian and Cassegrain) designs
- magnification and resolution
- light grasp and aperture
- digital detectors
- infrared telescopes
- radio telescopes and aperture synthesis
- effect of Earth's atmosphere on performance and other regions of EM spectrum

Orbital observation

- space telescopes
- observing outside optical and radio 'windows'
- ultraviolet, x-ray and gamma ray astronomy
- dark matter detection
- advantages and difficulties associated with orbital observing platforms
- escaping the Earth's gravity including escape velocity and rocket technology

Space exploration

- direct observation via manned missions including advantages and challenges
- the Apollo mission
- fly-by, orbiter, impacter and lander probes including recent examples and advantages/disadvantages of each design

Use of mathematics

- change the subject of an equation such as when using the equation for telescopic magnification (3b)
- substitute numerical values into algebraic equations using appropriate physical quantities (3c)

- solve simple algebraic equations (3d)
- translate information between graphical and numeric form (4a)
- plot two variables from experimental or other data (4b)
- determine the slope and intercept of a linear graph (4c)
- use angular measure in degrees (5a)
- use ratios and inverse square relationships such as when calculating telescopic magnification and light grasp (1c)
- use degrees, minutes and seconds of arc such as when considering telescopic resolution (5b)
- use the concept of subtended angle (5c)

Observational activities

23. Observational skills may be defined as the experience of using and applying specific astronomical knowledge, understanding and skills in a real out-of-classroom context. By undertaking observational work, students practise a range of skills, gain new insights into the Solar System and begin to appreciate the iterative nature of observations within astronomy. Observational work also requires students to practise a range of skills including research, planning, interpretation and evaluation.

24. Observational work is crucial to the development of skills and understanding in astronomy. Observational work ensures that students are given the opportunity to consolidate and extend their achievement through real experiences of the night sky. Specifications must require that observational work is carried out on at least two occasions, one of which should involve unaided observations (made with the naked eye or with the use of rudimentary equipment, for example shadow sticks) and the other aided observations (made with the use of binoculars, telescopes or robotic telescopes).

25. Specifications in GCSE astronomy must include an identifiable element or elements which develops observational skills. This will develop the knowledge, understanding and skills in paragraph 26. They should be developed through students' own experiences of observational work and students should also be able to relate this to unfamiliar contexts which may be based on exemplar data.

26. Specifications must require students to be able to demonstrate a range of observational knowledge, skills and understanding, developed through their observational work, including:

- planning an astronomical observation and describing how to carry it out safely and skilfully
- understanding the range of techniques and methods used in observational work
- analysing and interpreting qualitative and quantitative data from different sources

- evaluating the methods used and the data collected when carrying out an observation
- considering the validity and reliability of data in presenting and justifying conclusions

Appendix 1

Mathematical skills

The list below states the range and extent of mathematical techniques appropriate to GCSE specifications in astronomy.

1) Arithmetic and numerical computation

a) recognise and use expressions in decimal form

b) recognise and use expressions in standard form

c) use ratios, fractions, percentages and inverse square relationships

d) recognise and use logarithms (base 10) in equations and as scales and graphs

e) use a calculator to determine squares, square roots and cubes of positive numbers

2) Handling data

a) use an appropriate number of significant figures

b) find arithmetic means

c) use specialist units (AU, pc and Mpc with conversions to kilometres)

d) understand the principles of calculations involving light years (ly)

e) understand simple probability

f) make order of magnitude calculations

3) Algebra

a) understand and use the symbols: $=$, $<$, $<<$, $>>$, $>$, $\propto$, and ~

b) change the subject of an equation

c) substitute numerical values into algebraic equations using appropriate units for physical quantities

d) solve simple algebraic equations

4) Graphs

a) translate information between graphical and numeric form

b) plot two variables from experimental or other data

c) determine the slope and intercept of a linear graph

Geometry and trigonometry

a) use angular measures in degrees

b) use degrees, minutes and seconds of arc

c) use concept of subtended angle

d) use concepts of 3D motion, rotation and coordinates on a sphere: RA and Dec (celestial longitude and latitude)

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