Michigan Science Olympiad
2026 State Tournament
April 25th 2026

Astronomy C
Answer Key

Do not write in this packet

Directions:

- Each team will be given 50 minutes to complete this exam
- 3 sections: Section A (General), Section B (DSOs). Section C (Astrophysics)
- Use of internet or AI tools will result in immediate disqualification, Wi-Fi must be disabled in settings
- Use 2-3 decimal places in final answers for this test, partial credit will be given for work
- Final answers in Section C must be in the units requested by the question
- Tiebreakers (in order): Section C: 2k, 3f; Section A: 28, 32; Section B: 3a, 4d

Good luck!

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Section A (General)

[38 pts total, 1 pt each unless otherwise specified]

1	C	7	B	13	C	19	C	25	D
2	C	8	B	14	B	20	B	26	C
3	D	9	B	15	C	21	C	27	B
4	B	10	D	16	C	22	D	28	B
5	A	11	C	17	B	23	A	29	D
6	B	12	A	18	A	24	B	30	B

1. A star moving along the Horizontal Branch will be fusing what in the core?
    a. Hydrogen
    b. Helium
    c. Carbon
    d. Magnesium
2. What causes the high stellar mass loss observed on AGB stars?
    a. Rapid increase in surface temperature
    b. Decrease in stellar activity
    c. High stellar winds
    d. Depletion of hydrogen in the core
3. What occurs after the main sequence phase?
    a. Helium fusion becomes in the core immediately
    b. The star begins to increase in surface temperature rapidly
    c. The star enters the blue loop phase
    d. The star immediately begins expanding
4. The Sun's peak wavelength resides in the
    a. Infrared
    b. Visible
    c. UV
    d. X-Ray
5. By far the most common stellar remnant will be
    a. White Dwarf
    b. Neutron Star
    c. Black Hole
    d. Unknown

6. Stars moving along the Hayashi Track gravitationally collapse at a near constant temperature because
   a. Second ionization of Helium atoms in a stellar layer temperature around 10,000 K
   b. Convective transport allows for efficient heat transfer through layers
   c. Kelvin-Helmholtz Timescale is shorter than the Freefall Timescale
   d. Gravitational collapse with a high photosphere opacity
7. According to Kramer's Opacity Law utilized for stellar interiors, an increase in temperature leads to
   a. An increase in mean opacity
   b. A decrease in mean opacity
   c. Opacity is independent of temperature in Kramer's Law
   d. Opacity approaches an asymptote
8. Changes in the stellar interior are assumed to be
   a. Isothermal since temperature changes occur on a long timescale
   b. Adiabatic since heat is assumed to not lost to the "environment"
   c. Isentropic since interior stellar processes are assumed to have no entropy loss
   d. Isobaric since changes in the interior occur too quick for significant pressure changes
9. Some Cepheids rarely pulsate in the first overtone. What does this mean?
   a. The Cepheid has passed the first thermal pulse stage
   b. There exists one nodal line in the star's interior
   c. The period of pulsation matches the freefall timescale
   d. The Kappa Mechanism is powered by the first ionization of Hydrogen
10. The instability strip on the HR diagram includes what class of main sequence variable stars?
    a. ZZ Ceti
    b. PV Telescopii
    c. Alpha Cygni
    d. Delta Scuti
11. At what optical depth τ is considered to be the photosphere?
    a. 1/4
    b. 1/3
    c. 2/3
    d. 1
12. From your answer to question 11, what fraction of light escapes the photosphere? (hint $e^{-\tau}$)
    a. 50%
    b. 75%
    c. 80%
    d. 100%
13. The limit to the maximum radius for a given star in Hydrostatic Equilibrium is called
    a. Jeans Limit
    b. Roche Limit
    c. Hayashi Limit
    d. Edmund's Limit
14. In a uniform density approximation, the central pressure of a star is how many orders of magnitude off?
    a. 1

    b. 2
    c. 3
    d. 4
15. For a Brown Dwarf/"Failed-Star," generally these objects cease gravitationally collapsing after
    a. Lithium fusion begins in the core
    b. Deuterium fusion begins in the core
    c. Their cores become balanced by degeneracy pressure
    d. Their cores become highly opaque
16. What is the definition of a stellar isochrone?
    a. A stellar population that consists mostly of hot high-mass blue stars
    b. Plot of stars that are the same temperature but different masses
    c. Plot of stars on the HR diagram with the same age but different masses
    d. A stellar cluster of young cool red stars
17. The period-luminosity (not absolute magnitude) relationship for a Cepheid Variable star is modelled as
    a. Linear
    b. Exponential
    c. Logarithmic
    d. Quartic
18. What is the best part of the EM spectrum to observe HII regions?
    a. Visible
    b. Infrared
    c. UV
    d. X-ray
19. Starquakes waves, analogous to Earthquakes, travel at what speed inside a star?
    a. Speed of Light
    b. Speed of Refraction
    c. Speed of Sound
    d. Speed of Diffraction
20. In the Triple-Alpha Process of fusing Helium into Carbon, what intermediate element is temporarily created?
    a. Lithium
    b. Beryllium
    c. Boron
    d. Nitrogen
21. If a supernovae were to occur, what would be the first flux of particles detected?
    a. Photons
    b. Leptons
    c. Neutrinos
    d. Quarks
22. Besides conservation of angular momentum after a supernovae, how else can neutron stars increase their rotation rate?
    a. Conversion of luminosity into rotational energy
    b. There is no other mechanism to explain how neutron stars can increase their rotation
    c. Inversion of their strong magnetic fields

d. Mass accretion in a binary system

23. Recurrent Novae depend on mass transfer in a binary from which lagrange point?
    a. L1
    b. L2
    c. L3
    d. L4
24. Knowing the proper motion of a star relative to its star cluster allows astronomers to determine
    a. The age of the star
    b. If it is a runaway star
    c. The approximate composition of the star
    d. The temperature of the star
25. In astrophysics, a "scale height" for a value is defined as
    a. A length/depth where a fluid reaches equilibrium
    b. A length/depth where an atmosphere levels off and approaches 0 or infinity
    c. The length/depth at which stellar structure equations cannot accurately predict stellar conditions
    d. The length/depth for a value to decrease by a factor of e (2.718)
26. The pulsation period for a variable star will always be greater than what other timescale?
    a. Nuclear Timescale
    b. Kelvin-Helmholtz/Thermal Timescale
    c. Freefall Timescale
    d. Roche Timescale
27. Why do low mass stars have radiative cores while high mass stars have convective cores?
    a. Low mass stars do not have a core hot enough to be convective
    b. Low mass stars have a low temperature gradient
    c. High mass stars have a core too hot to be radiative
    d. High mass stars have a low temperature gradient
28. A star has an effective temperature and solar luminosity, respectively, of 4000 K, $100\ L_{\odot}$. What is the star's Yerkes Classification? [TB]
    a. K6 V
    b. K6 III
    c. M3 II
    d. M6 Ib

Questions 29 - 31 will refer to Image A on the image sheet.

29. As solar mass increases, the evolutionary tracks flatten and become more horizontal. Why is this the case?
    a. At higher masses, protostars stay convective and thus remain at a relatively constant luminosity
    b. Higher mass protostars collapse slower into the mains sequence
    c. At higher masses, changes in temperature affect luminosity less due to convection currents
    d. Higher mass protostars quickly develop low opacity/radiative cores that allow energy to escape
30. The numbers to the right of the graphs represent what timescale?
    a. Dynamical Timescale

b. Kelvin-Helmholtz Timescale
c. Photon Diffusion Timescale
d. Nuclear Timescale

31. What is characteristic about the cores of protostars on the blue vertical drops in the graph? [2]
These stars have convective cores (+2)

Questions 32 - 34 will refer to Image C on the image sheet.
Assume m_1 to be the primary star and that eclipses enclose an entire disk

32. Determine the luminosity of m_2. [2, TB]
Accept $[0.55,\ 0.85]\ L_\odot$ (+2)
33. What spectral class and evolutionary type would you expect m_1 to be, based on its properties? [2]
K class (+1), half points for M class
Main Sequence (+1)
34. Convert the total system luminosity to an absolute magnitude. [2]
Accept $[3.9,\ 4.1]$ (+2)

Section B (DSO)

[40 pts total]

1) The Orion Nebula on the cover of this exam packet was taken at the University of Michigan Angell Hall Observatory (Go Blue!) [8 pts total]
   a) Identify the stars that the arrow is pointing to [1]

      Theta-1 Orionis (must include the 1)

   b) What is the name of the open cluster formed by the stars from part a? [1]

      Trapezium Cluster

   c) The age of the open cluster is estimated to be 300,000 years old. What is the maximum mass (in solar masses) of a main sequence star inside this open cluster? [3]

$$10^{10}\left(M/M_{\odot}\right)^{-2.5} = 300,000\ years$$

Accept $[64,\ 65]\ M_{\odot}$

   d) The highest mass pre-main sequence stars would be classified as what stars? [1]

      Herbig Ae/Be Stars

   e) The most prominent emission from the Orion Molecular Cloud Complex in cold regions comes from what compound? [2]

      Carbon Monoxide

2) The following questions will refer to Image B on the image sheet. [8 pts total]
   a) Identify Image B. [1]

      HP Tauri

   b) This object was identified to have high Fe abundance. Predict what stellar population it belongs to; what does this imply about its relative age? [2]

      Population I; relatively young

   c) What is the name of the reflection nebula surrounding this object? [2]

      Magakian 77 / GN 04.32.8 / DG 41 / Bernes 83

   d) This object displays Hα emission. Based on this, what part(s) of the EM spectrum would be best for viewing it? [1]

      Visible or IR

   e) Which part of this system is most similar to the Sun? Due to the bloated appearance of this element, and its presence in a multistar system, what event is predicted to have formed it? [2]

      G2; A merger event

3) The following questions will refer to Image E , an emission spectrum of the Helix Nebula (NGC 7293). [9 pts total]
   a) The emission line of Ne III is shown in the spectrum. How many ionizations is the Ne III line? (singly, doubly, triple, etc) [3, TB]

      Doubly Ionized (+2). Ne I denotes neutral Neon, Ne III is Ne 2+ (+1)

b) The presence of elements heavier than Carbon, like Neon and Sulfur, in the spectrum is indicative of what? [1]

The progenitor star was likely very massive and able to fuse carbon into heavier elements.

c) Based on the emission spectrum, it appears the progenitor star produced the most of which metal? [1]

Oxygen (the O IV emission line has the highest intensity)

d) Over time, the Helix Nebula will cool and the emission lines of ionized Neon, Oxygen, and Sulfur will regain their lost electrons. Why does this decrease the opacity of the nebulae? [3]

Less free electrons can scatter photons (through Thompson Scattering)

e) The relatively high ionization energies of Ne III and Ne V are produced by what EM wave? [1]

X-rays

4) The following questions will refer to Image G, a radial velocity curve of WDJ181058.67+311940.94. [10 pts total]

a) Is this system moving closer to or away from Earth? At what velocity? [1]

Moving away at 50 km/s

b) What is the observed amplitude of Star 2? [2]

50 km/s - (-45 km/s) = 95 km/s, Accept [90, 100] km/s

c) This binary system is observed to have an inclination of ~40 degrees. What is the true amplitude of Star 2? [2]

$\frac{95\ km/s}{sin(40\ deg)} = 134.35\ km/s$, Accept [133, 135] km/s

d) Based on simulations of the binary merger, what is the brightest V band apparent magnitude of the detonation? [2, TB]

$m_V = -16.1$

e) The brightest absolute magnitude of the merger is estimated to be $M_V = -17.8$. Is this dimmer than the average Type Ia supernova? How is Nickel-56 involved? [3]

It is dimmer than the average Type Ia SN. (+1)

This is because there is not a lot of Nickel-56 in the stars, which when decaying into Cobalt, produces photons. (+2)

5) The following questions will pertain to Mira (Omicron Ceti). [5 pts total]

a) Identify the image with Omicron Ceti [1]

Image J

b) What is occurring between the two components in this system? [1]

Mass Transfer

c) According to research, the current mass of the disk around Mira B is less than what planet in the Solar System? [2]

Jupiter

d) Omicron Ceti is a special type of binary star system called what? [1]

Symbiotic Stars

Section C (Astrophysics)

(38 pts total)

1) **Telescopic Resolution [4].** Astronomers have countless images of our solar system, nebulae, and star clusters, but very few direct images of stars. Assume the small angle approximation for the following two questions. For some comparisons, a table of telescope apertures are provided.

Telescope	Aperture
Galileo's Refractor	37 mm
Average Toy/Market Telescope	10 mm - 0.3 m
Hubble	2.4 m
Keck Observatory	2 x 10 m

a) Alpha Centauri A has a diameter of $1.7 \cdot 10^{9}\ m$ and is $4.1 \cdot 10^{16}\ m$ from Earth. What is the minimum aperture required (<u>in meters</u>) for a telescope to resolve α Centauri A in visible light (550 nanometers)? [2]

$$\theta'' = 206265(1.7e9\ m\ /\ 4.1e16\ m) = 0.0086''$$

$$\Delta\theta\ [arcsec] = 0.0086'' = 251643\frac{550\cdot 10^{-9}\ m}{d\ [m]}, \qquad d = 16.09\ m$$

Astronomers use a technique called Interferometry to achieve very high angular resolutions. By using an array of separate telescopes and combining wave interference patterns, interferometry can obtain angular resolutions proportional to the inverse of the distance between the center of each telescope mirror.

b) Image F shows a layout of the Keck Observatory. What would be the theoretical angular resolution (in arcseconds) of the Keck Observatory in visible wavelength (550 nanometers)? [2]

$$\Delta\theta\ [arcsec] = 251643\frac{550\cdot 10^{-9}\ m}{85\ m} = 0.0016''$$

2) **Neutron Star Spindown [18].** Neutron stars are one of the most exotic stellar objects, particularly for their rapid rotation rates, caused by the (partial) conservation of angular momentum after a supernova. However, this rotation rate is not constant and energy is slowly radiated away through other mechanisms. The spindown luminosity of a neutron star refers to the energy radiated away from a pulsar's decaying rotation. The following questions will pertain to the Crab Pulsar in the M1.

The moment of inertia for a uniform density sphere is given by $I = \frac{2}{5} M R^2$

a) How do pulsars slow their rotation rate over time? [1]

Magnetic Dipole Radiation. The pulsar's unaligned magnetic field relative to its poles induces electric fields around the pulsar, which in turn produce electromagnetic radiation that causes the pulsar to lose energy/angular momentum

Astrophysicists are attempting to derive a relation between the spindown luminosity L and factors such as mass M, radius R, angular velocity ω, and angular deacceleration α.

All units will be in SI

They confirm this system satisfies Buckingham's Theorem of Dimensional Analysis:

With n variables - k dimensions = 4 - 3 = 1 dimensionless variable C.

q_n are all nonzero integers (non-decimal).

$$L = C \cdot M^{q_1} \cdot R^{q_2} \cdot \omega^{q_3} \cdot \alpha^{q_4} \qquad (q_n \neq 0)$$

Writing in Dimensional Form:

$$\left[\frac{kg m^2}{s^3}\right] = [kg]^a \cdot [m]^b \cdot \left[\frac{1}{s^3}\right]^c$$

b) Solve for for q_1, q_2, q_3, and q_4 based on the dimensional form for spindown luminosity. [3]

kg: $1 = a$

m: $2 = b$

s: $-3 = -3c$

Since $c = 1 \Rightarrow \left[1/s^3\right]^1$, ω has units of 1/s and α has units of $1/s^2$ then:

$$n_3 = 1, \qquad n_4 = 1$$

$$L = C \cdot M \cdot R^2 \cdot \omega \cdot \alpha$$

c) What is the expected value of C? [1]

$\frac{2}{5}$ or $-\frac{2}{5}$ accepted. Note that $L = C \cdot M \cdot R^2 \cdot \omega \cdot \alpha$ contains CMR^2.

For a sphere, $C = 2/5$

Proof: $L = -\frac{dE}{dt} = -\frac{d}{dt}\left[\frac{1}{2}I\omega^2\right] = -I\omega\frac{d\omega}{dt} = -\left(\frac{2}{5}MR^2\right)\omega\alpha$

d) Image D on the image sheet shows a graph called a periodogram, showing the signal strength of frequencies that are detected from the pulsar. Which frequency is the actual rotation period of the pulsar? Why are there multiple detected frequencies? [2]

30.30 Hz.

There are multiple detected frequencies because they are integer multiples of the "base frequency."

e) From your first answer to part d, find the rotation period in milliseconds (not hertz) of the Crab Pulsar. [1]

$30.30\ Hz = 1/P, \quad P = 33\ ms$

f) The formula for rotational kinetic energy is $K_{rot} = \frac{1}{2}I\omega^2$. What is the rotational energy of the Crab Pulsar in joules? Assume a mass and radius of $2\ M_\odot$ and 10 km respectively. [1]

$$K_{rot} = \frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{2}{5}(2 \cdot 1.99e30\ kg)(10e3\ m)^2\right)\left(\frac{2\pi}{33\cdot 10^{-3}\ s}\right)^2 =$$

$$2.89 \cdot 10^{42}\ J$$

The rate of angular deacceleration generated from rotational energy loss is

$$\alpha = -\frac{5L}{2MR^2\omega_{initial}}$$

g) The Crab Nebula Pulsar's spindown luminosity is estimated to be $3 \cdot 10^{31}\ W$. What is the angular acceleration of the Crab Nebula Pulsar? [1]

$$\alpha = -\frac{5L}{2MR^2\omega_{initial}} \Rightarrow -\frac{5\left(3\cdot 10^{31}\ W\right)}{2\left(2\ M_\odot\right)(10e3\ m)^2\left(\frac{2\pi}{33e-3\ s}\right)} = -9.9 \cdot 10^{-10}\left[\frac{1}{s^2}\right] \text{(sign must be correct)}$$

h) Within an order of magnitude, calculate how long it would take for the Crab Pulsar to dissipate all its rotational energy. [2]

$$0 = \omega_f = \omega_i + \alpha t, \qquad t = -\frac{\omega_i}{\alpha} = -\frac{\left(\frac{2\pi}{33e-3}\right)s^{-1}}{-9.9\cdot 10^{-10}\ s^{-2}} \Rightarrow 6100\ years$$

Accept anything within 3000-6000 years

With the rate of angular deacceleration known, it is possible to derive the rate that the pulsar's period increases, denoted by $\dot{P}$.

$$\dot{P} = -\frac{2\pi}{\omega^2}\alpha = \frac{2\pi}{\omega^3}\left(\frac{L}{I}\right)$$

i) What are the units of $\dot{P}$? [1]

Unitless, it is the time rate at which a period of time decreases: $\dot{P} = \frac{dP}{dt} = \frac{seconds}{seconds}$

j) What is the value of $\dot{P}$ for the Crab Pulsar? [2]

$$\dot{P} = \frac{2\pi}{\omega^3}\left(\frac{L}{I}\right) = \frac{2\pi}{\left(\frac{2\pi}{33e-3}\right)^3}\left(\frac{3\cdot 10^{31}\ W}{\frac{2}{5}(2\cdot 1.99e30\ kg)(10e3\ m)^2}\right) = 1.72\cdot 10^{-13}$$

k) How many nanoseconds ($10^{-9}\ s$) per day is the period of the Crab Pulsar increasing according to our model? The actual rate of period increase is 38 ns/day. [3, TB]

$$1.72\cdot 10^{-13}\ \frac{s}{s} \times \frac{24\cdot 60\cdot 60\ s}{1\ Day} \times \frac{10^9\ ns}{1\ s} = 14.86\ ns/day$$

3) **Pleiades Cluster Dynamics [16].** The Pleiades Star Cluster of stars has the approximate HR diagram shown in Image I on the image sheet. The cluster is, on average, 444 ly away from Earth.

The formulae and constants below may be utilized:

$$U = -\frac{3GM^2}{5R}$$

$$T_{Surface} = 4600\ K\left(\frac{1}{0.92(B-V)+1.7} + \frac{1}{0.92(B-V)+0.62}\right),$$

MS Mass-Luminosity: $L/L_\odot = 1.4(M/M_\odot)^{3.5}$ $\quad (2\ M_\odot < M < 55\ M_\odot)$

$$M_{Bolometric,\ Sun} = 4.74$$

a) Why is a color index (like B-V) used on some HR diagrams? [1]

Temperature cannot be directly measured from stars (need radius and luminosity). So by measuring the star's apparent magnitude in blue light (B) and visible light (V), the relative fluxes from these filters can yield the approximate temperature of the star.

The main sequence turnoff point lies at $(-0.1,\ 3.5)$.

b) At what temperature in K does this occur? [1]

$$T_{Surface} = 4600\ K\left(\frac{1}{0.92(-0.1)+1.7} + \frac{1}{0.92(-0.1)+0.62}\right) = 11572.8\ K$$

c) What stellar classification does this occur? What Morgan-Keenan classification are these stars evolving towards? [2]

B (main sequence), IV (Subgiant Branch)

d) Do the Pleiades still have protostars? Where are they on the HR Diagram? [2]

Above and to the right of the Main Sequence, about (1.3, 8), there are 3 of them.

e) At what solar luminosity does the main sequence turnoff point occur? [2]

$$3.5 - M = -5 + 5log\left(444\ ly\ \frac{1\ pc}{3.26\ ly}\right)$$

$$M = -2.17$$

$$4.74 - (-2.17) = 2.5log\left(\frac{L_{Turn}}{1\ L_\odot}\right), \qquad L_{Turn} = 580.76\ L_\odot$$

f) Estimate the age of the Pleiades Star Cluster in myr. [2, TB]

$$L/L_\odot = 1.4(M/M_\odot)^{3.5} \Rightarrow 580.76\ L_\odot = 1.4(M/M_\odot)^{3.5}$$

$$M = 5.60\ M_\odot$$

$$10^{10}(5.60\ M/M_\odot)^{-2.5} = 134.75\ myr$$

Estimating the Pleiades roughly as a spherical cluster, the average velocity of stars in this system can be approximated. The Pleiades has a total mass of 800 $M_\odot$ and a half-light radius of 10 ly.

g) From the virial theorem $2K + U = 0$, estimate the average velocity of a star in this cluster in m/s. [3]

$$2\sum \frac{1}{2} m_{star} v^2 + \left(- \frac{3GM_{total}^2}{5R} \right) = 0$$

$$\frac{1}{2} M_{total} \left(\bar{v}\right)^2 = \frac{3GM_{total}^2}{10R}$$

$$M_{total} = 800\ M_\odot \cdot 1.99e30\ kg/M_\odot = 1.592e33\ kg$$

$$R = 10\ ly \cdot 9.46e15\ m/ly = 9.46e16\ m$$

Final answer: $\bar{v} = 820\ m/s$

h) Ground based observatories track a star (444 ly away) that is observed to have a radial velocity 0.2 km/s of and proper motion of 2 milliarcseconds/yr. Based on its total space velocity, what would the star be classified as? Image L may be useful. [3]

$$2\ mas/yr = 206265 \cdot 10^3 \left(\frac{v_{tangential}\ [m/yr]}{444\ ly \cdot 9.46e15\ m/ly} \right)$$

$$v_{tangential} = 4.07 \cdot 10^{10}\ m/yr \Rightarrow 1290.6\ m/s, \qquad v_r = 0.2 \cdot 10^3\ m/s$$

$$v = \sqrt{v_{RV}^2 + v_p^2} = 1306\ m/s$$

Since $v > \bar{v}$, the star is a **runaway star**