Introductory Astronomy **NAME:**

Homework 7: Spectra: Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems (∼ 50–70 %) will turn up on exams.

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001 qmult 00007 1 4 1 easy deducto-memory: reading-homework-self-testing done 2

1. Did you complete reading-homework-self-testing for the Introductory Astronomy Lecture (IAL) by the weekly due date?

   a) YYYessss! b) Jawohl! c) Da! d) Sí, sí. e) OMG no!

   SUGGESTED ANSWER: (a),(b),(c),(d)

   Wrong answers:
   e) As Lurch would say AAAARGH.

   Redaction: Jeffery, 2008jan01

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007 qmult 00150 1 4 1 easy deducto-memory: heat energy defined

2. Internal energy or heat energy is:

   a) statistically distributed forms of the other kinds of energy: most notably microscopic kinetic energy, microscopic potential energy, and electromagnetic radiation.
   b) temperature.
   c) the opposite of cold.
   d) the microscopic cause of friction.
   e) an invisible fluid that causes temperature.

   SUGGESTED ANSWER: (a)

   However I've given a longer definition than in class in order to be more accurate: but this may only confuse people.

   Wrong answers:
   b) The first misconception about heat that is dealt with in any course. In any case, heat is an extensive quantity, temperature an intensive one.
   c) Actually coolness would be closer to an opposite. Hot is closer to the opposite of cold.
   d) The microscopic cause of friction are electromagnetic forces which often do depend on temperature in some way.
   e) Shades of the old phlogiston theory where heat was a substance.

   Redaction: Jeffery, 2001jan01

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007 qmult 00200 2 4 4 moderate deducto-memory: hot bodies radiate

3. Any body (including a cloud of dilute gas) at a nonzero temperature or range of temperatures will radiate (in addition to any reflected light):

   a) a pure line spectrum. b) a perfect blackbody spectrum. c) only X-rays.
   d) electromagnetic radiation. e) nothing at all.

   SUGGESTED ANSWER: (d)

   It's just a wee bit tricky I think to rule out perfect blackbody spectrum.

   Wrong answers:
   a) In strictest sense I doubt that anything emits a pure line spectrum, but obviously some things are close enough.
   b) In strictest sense I doubt that anything emits a perfect blackbody spectrum, but obviously some things are close enough. But a dilute gas doesn't: it emits a line spectrum.
   c) Obviously not.
   e) Nah.

   Redaction: Jeffery, 2001jan01

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007 qmult 00210 1 1 3 easy memory: blackbody spectrum and temperature 1

4. A solid, liquid, or dense gas at a uniform temperature (in addition to any reflected light) will:

a) radiate a line spectrum.
b) radiate a greybody spectrum.
c) radiate a blackbody spectrum which is a fundamentally important spectrum whose shape depends only on the absolute (i.e., Kelvin scale) temperature of the radiating body.
d) have a uniform color that depends only on the shape of the radiating body.
e) radiate nothing.

SUGGESTED ANSWER: (c)

Wrong answers:
b) A greybody spectrum?

Redaction: Jeffery, 2001jan01

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007 qmult 00350 1 3 2 easy math: using Wien's law for a star

5. Wien's law for blackbody spectra is

$$\lambda_{\mu\text{m}}^{\text{max}} = \frac{2897.771955\ldots\,\mu\text{m}\,\text{K}}{T} .$$

Say one has a stellar spectrum with a maximum wavelength at $0.5\,\mu$m (i.e., 0.5 microns). What is the star's approximate photospheric temperature?

a) 600 K. b) 6000 K. c) 20000 K. d) 31416 K. e) 6000 nm.

SUGGESTED ANSWER: (b) If one remembers the maximum wavelength of the Sun and the Sun's photospheric temperature, then it becomes a memory question.

Wrong answers:
e) Wrong units.

Fortran-95 Code

```
          print*
          print*,"Wien's law constant for wavelength."
          xold=5.0_np
          do
            x=5.d0*(1.0_np-exp(-xold))
            if(x .eq. xold) exit
            xold=x
          end do
          h=6.62607015e-34_np    ! exact
http://physics.nist.gov/cuu/Constants/Table/allascii.txt
    !       1 23456789a
          clight=2.99792458d8
          b=1.380649e-23_np      ! exact
https://physics.nist.gov/cuu/Constants/Table/allascii.txt
    !       1 23456789
          con=(h*clight/b)/x  ! https://en.wikipedia.org/wiki/Wien ... derivation
          print*,'x,con'
          print*,x,con
    !  4.9651142317442763037   2.8977719551851726614 5E-0003
    !  4.965114231744276       2.897771955185172 *10**(-3)
           !
https://en.wikipedia.org/wiki/Wien%27s_displacement_law#Derivation_from_Planck's_law
    !                          2.897771955 ... 10**(-3)   !
http://physics.nist.gov/cuu/Constants/Table/allascii.txt
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Redaction: Jeffery, 2001jan01

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007 qmult 00460 2 5 3 moderate thinking: Earth's blackbody temperature

6. A true blackbody absorbs all the electromagnetic radiation that hits it (i.e., it does not reflect any electromagnetic radiation) and has a uniform temperature. Let us treat the Earth as blackbody, except

that it reflects that fraction of light that it actually does reflect. The light gathering surface area of the Earth is

$$\pi R_{\oplus}^2 ,$$

where $\pi = 3.14159265\ldots$ is pi, a pure number, and $R_{\oplus}$ is the Earth radius. The total light energy gathered per unit time by the Earth is thus

$$f(1-a)\pi R_{\oplus}^2 , \tag{1}$$

where $f = 1367.6$ watts per square meter is the mean solar constant and $(1-a) = 0.694$ is a factor accounting for the reflection of electromagnetic radiation from the Earth (Wikipedia: Earth: Bond albedo).

As a blackbody (except for the reflection correction), the Earth radiates a total energy per unit time of

$$A\sigma T^4 , \tag{2}$$

where

$$A = 4\pi R_{\oplus}^2$$

is the surface area of the Earth and σT^4 is the Stefan-Boltzmann law (i.e., the energy radiated per unit area per unit time by a blackbody). The constant $\sigma = 5.670373 \times 10^{-8}$ in mks units.

Since the Earth is neither a net energy gainer or loser (at least not to an extent important for this problem), expression (1) must equal expression (2) to maintain a constant thermal energy content on Earth. Equating the expressions, we obtain:

$$f(1-a) = 4\sigma T^4$$

or

$$T = \left[\frac{f(1-a)}{4\sigma}\right]^{1/4} = 254\,\mathrm{K} .$$

This temperature is called the blackbody or effective temperature of the Earth.

a) At 254 K, the Earth would be way hotter than the boiling point of water. The reason the Earth isn't this hot is because the Earth is not actually a blackbody.
b) At 254 K, the Earth would be colder than the freezing point of water. The reason the Earth isn't this cold is because of the greenhouse **COOLING** effect.
c) At 254 K, the Earth would be colder than the freezing point of water. The reason the Earth isn't this cold is because of the greenhouse **HEATING** effect.
d) At 254 K, the Earth is at a comfortable temperature for life. Our simple analysis shows why life is possible on Earth. The same analysis for Venus and Mars would show why life as we know it would be unlikely there. Both Venus and Mars would be too cold. (Venus would be too cold despite being located closer to the Sun because of its high reflectivity.)
e) At 254 K, Mars is at a comfortable temperature for life. Nevertheless, life there seems unlikely.

SUGGESTED ANSWER: (c)

The trick question. The preamble is hard, but the students don't do the algebra or the math. They just assess the result.

Wrong answers:
a) Above boiling temperature: not on the Kelvin scale.
b) Greenhouse cooling effect?
d) -18°C is comfortable?
e) Mars isn't at issue.

Fortran Code

```
          print*
          solcon=1367.6d0  !1367.6
http://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html 2013
          aa=.306d0        ! https://en.wikipedia.org/wiki/Earth Bond albedo
```

```
          sigma=5.670373d-8 !
https://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law
          temp=( solcon*(1.d0-aa)/(4.d0*sigma) )**.25d0
          print*,'temp'
          print*,temp
!              254.33828342338919
```

Redaction: Jeffery, 2001jan01

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007 qmult 00510 1 1 3 easy memory: ion defined
Extra keywords: CK-110-ion

7. An ion is a:

   a) synonym for an atom. b) neutral atom. c) charged atom. d) molecule.
   e) proton.

SUGGESTED ANSWER: (c)

Wrong answers:
e) Well a bare proton is the hydrogen ion, but an ion is not a proton.

Redaction: Jeffery, 2001jan01

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007 qmult 00550 1 1 1 easy memory: spectral line spectrum
Extra keywords: CK-100,110

8. The line spectrum of an atom, ion, or molecule is:

   a) an almost unique identifier of the atom, ion, or molecule.
   b) the radiation emitted when the temperature of the atom, etc., goes over 1000 K.
   c) the radiation emitted when the temperature of the atom, etc., goes over 10,000 K.
   d) the radiation emitted when the temperature of the atom, etc., goes over 25,000 K.
   e) never observed from astronomical bodies outside of Solar System.

SUGGESTED ANSWER: (a)

Wrong answers:
e) If this were true, we wouldn't know what the universe was made of.

Redaction: Jeffery, 2001jan01

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007 qmult 00570 2 4 4 moderate deducto-memory: H-alpha line wavelength

9. The Hα line (AKA the H-alpha line), usually the strongest **VISIBLE** line of hydrogen, has a wavelength of 656 nm It is a/an ____________ line.

   a) X-ray b) ultraviolet c) radio d) red e) red and blue

SUGGESTED ANSWER: (d)

Wrong answers:
e) This not logically possible, unless one starts making special qualifications: e.g., consider strongly Doppler shifted versions of the line. But special cases are not best answers.

Redaction: Jeffery, 2001jan01

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007 qmult 00610 1 4 1 easy deducto-memory: photosphere defined 1
Extra keywords: CK-249,266, Sun-question

10. The layer of a star (e.g., the Sun) from which most of the emitted electromagnetic radiation comes is called the:

    a) photosphere. b) chromosphere. c) hemisphere. d) core. e) corona.

SUGGESTED ANSWER: (a)

Wrong answers:
d) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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007 qmult 00650 3 1 2 tough memory: Sun's absorption line spectrum

11. The Sun emits a spectrum that is approximately a blackbody spectrum. It isn't exactly a blackbody spectrum because, among other reasons:

    a) the photospheric emission forms over a range of temperatures and there is an **EMISSION LINE SPECTRUM** superimposed on the photospheric emission.
    b) the photospheric emission forms over a range of temperatures and there is an **ABSORPTION LINE SPECTRUM** superimposed on the photospheric emission.
    c) the photospheric emission forms at a single temperature.
    d) the coronal emission is almost equal to the photospheric emission.
    e) convective layer of the Sun is so huge: about 2/7 solar radii deep.

    SUGGESTED ANSWER: (b)

    Wrong answers:
    a) not an emission line spectrum: this takes memory for most students.
    c) this isn't likely and was denied in book and (one hopes) in the lectures.
    d) No it isn't. This should be memorable from several points of of view. We don't ordinarily see the huge corona right.
    e) a red herring.

    Redaction: Jeffery, 2001jan01

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007 qmult 00730 1 1 1 easy memory: Doppler effect defined for light

12. The Doppler effect for light causes:

    a) the wavelength of a wave phenomenon to change (or shift) when its **SOURCE AND RECEIVER** are moving with respect to each other along the source-receiver line.
    b) the wavelength of a wave phenomenon to change (or shift) when its **SOURCE** (but **NEVER** its **RECEIVER**) is moving along the source-receiver line.
    c) the wavelength of a wave phenomenon to change (or shift) when its **RECEIVER** (but **NEVER** its **SOURCE**) is moving along the source-receiver line.
    d) the Sun to appear redder at sunset and sunrise than at midday.
    e) the Sun to appear redder at midday than at sunset and sunrise.

    SUGGESTED ANSWER: (a)

    One does have to understand that relative motion is the key thing.

    Wrong answers:
    e) Nah.

    Redaction: Jeffery, 2001jan01

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007 qmult 00750 2 4 1 moderate deducto-memory: Doppler shift

13. One light source is moving directly away from you; another light source is moving exactly perpendicular to your line of sight to it for the length of time of the observation: i.e., its moving on a **CIRCLE** centered on you.

    a) The first source is Doppler shifted to the **RED** (i.e., to longer wavelength). The second source is **NOT** significantly Doppler shifted unless its velocity is not small compared to the vacuum speed of light.
    b) The first source is Doppler shifted to the **BLUE** (i.e., to shorter wavelength). The second source is **NOT** significantly Doppler shifted unless its velocity is not small compared to the vacuum speed of light.
    c) **NEITHER** source is Doppler shifted. There can only be a Doppler shift if the velocity is specified in the problem.
    d) **BOTH** sources are Doppler shifted to the **RED** by about the same amounts.
    e) **NEITHER** source is Doppler shifted. There can only be a Doppler shift when the source is approaching the receiver.

    SUGGESTED ANSWER: (a)

Wrong answers:

e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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007 qmult 00760 3 5 5 tough thinking: Doppler effect and line spectra

14. The lines of atomic line spectra are not infinitely narrow in wavelength. There is a natural intrinsic width which is broadened by thermal and collisional effects. But let's ignore those effects for this question. How would an atomic line from a rapidly rotating star appear different from the same atomic line as measured in the laboratory?

a) The star line would be divided into three lines: a fast line, a slow line, and an intermediate line.
b) The star line would **NARROWER** due to the Doppler effect.
c) The star line would be expanded into a blackbody spectrum by the rotation.
d) The star line would be **BROADER** due to the Doppler effect. The part of the star moving toward the observer would broaden the line in the **LONG WAVELENGTH (REDWARD) DIRECTION**. The part of the star moving away from the observer would broaden the line in the **SHORT WAVELENGTH (BLUEWARD) DIRECTION**.
e) The star line would be **BROADER** due to the Doppler effect. The part of the star moving toward the observer would broaden the line in the **SHORT WAVELENGTH (BLUEWARD) DIRECTION**. The part of the star moving away from the observer would broaden the line in the **LONG WAVELENGTH (REDWARD) DIRECTION**.

SUGGESTED ANSWER: (e)

Can students put the Doppler effect and line spectra together?

To explicate, a star emits a spectral line from all parts of its surface facing the Earth. For simplicity, let's say the star's center of mass is at rest with rexpect to the Earth. The part of the surface at rest with respect to the Earth is a diagonal aligned with the rotation axis. This diagonal will emit at the rest-frame wavelength of the spectral line. The rest of the star will be moving toward or away from the Earth. The side moving toward/away has a continuum of velocities relative to the Earth, and so will give a continuum of blueshifted/redshifted emission that will broaden the observed line blueward/redward of the rest-frame wavelength of the line.

Wrong answers:

a) red herring for people who are vaguely thinking of the Zeeman effect.
b) the Doppler effect would do the reverse. If people read the other answers, this would probably become clear.
c) complete red herring.
d) the follow up description is wrong. Moving away causes redshift. Moving toward causes blueshift.

Redaction: Jeffery, 2001jan01