

# Exercise 1.0

## THE CELESTIAL EQUATORIAL COORDINATE SYSTEM

Equipment needed: A celestial globe showing positions of bright stars and Messier Objects.

### I. Introduction

There are several different ways of representing the appearance of the sky or describing the locations of objects we see in the sky. One way is to imagine that every object in the sky is located on a very large and distant sphere called the **celestial sphere**. This imaginary sphere has its center at the center of the Earth. Since the radius of the Earth is very small compared to the radius of the celestial sphere, we can imagine that this sphere is also centered on any person or observer standing on the Earth's surface. Every celestial object (e.g., a star or planet) has a definite location in the sky with respect to some arbitrary reference point. Once defined, such a reference point can be used as the origin of a celestial coordinate system. There is an astronomically important point in the sky called the **vernal equinox**, which astronomers use as the origin of such a celestial coordinate system. The meaning and significance of the vernal equinox will be discussed later.

In an analogous way, we represent the surface of the Earth by a globe or sphere. Locations on the geographic sphere are specified by the coordinates called **longitude** and **latitude**. The origin for this geographic coordinate system is the point where the Prime Meridian and the Geographic Equator intersect. This is a point located off the coast of west-central Africa. To specify a location on a sphere, the coordinates must be angles, since a sphere has a curved surface. Hence, longitude and latitude are angular distances from the origin described above. Longitude is measured west or east from the origin (or prime meridian), and latitude is measured north or south from the origin (or geographic equator). If a ship happens to be located exactly at the geographic origin, we would say it has a longitude of 0 degrees (also written  $0^\circ$ ) and latitude of  $0^\circ$ .

When one uses the celestial sphere to represent the sky, any measurements of position must also be angles. As on a geographic globe, two such angles are necessary to uniquely specify the location of any object on the celestial sphere. The two angles or coordinates that astronomers use to specify position with respect to the vernal equinox are called **right ascension** and **declination**.

A peculiar thing about right ascension is that, though it is an angle, it is usually expressed in time units, that is, hours, minutes and seconds of time. This is because there is a definite relationship between right ascension and something called **sidereal time** (sidereal time will be defined and studied in another, later exercise). An analogous relationship exists between longitude and time. A star located exactly at the vernal equinox would have a right ascension of 0 hours, 0 minutes (other ways of designating this are  $0^h 00^m$  or 0:00) and a declination of 0 degrees, 0 arcminutes ( $0^\circ 00'$  or 0:00).

**Note: Do not confuse minutes of time with arcminutes, they are not the same. See part II.**

Our objective now will be to use a model of the celestial sphere to locate objects using the coordinates right ascension (**RA** or  $\alpha$ ) and declination (**Dec** or  $\delta$ ). But first, we shall undertake a review of angular or arc measurement and how it is expressed and symbolized.

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### II. Angular or Arc Measurement.

Any circle can be divided into any number of equal parts. For example, imagine dividing a circle into 4 equal parts. Any of these parts is called an **arc** and would be a certain fraction of the circumference of the circle; in this case, one fourth of a circumference. The ancient Babylonians found it convenient to divide a circle into 360 equal parts, which we call **degrees**. Thus,

**One degree is 1/360th of a circle's circumference.**

The Babylonians had an apparent fixation on multiples of 60, so they further divided each degree into 60 equal parts called arcminutes, or minutes of arc. That is,

**1 arcminute (1') is 1/60th of a degree.**

To allow for greater precision, they decided to divide each arcminute into 60 equal parts called arcseconds, or seconds of arc. Hence,

**1 arcsecond is 1/60th of an arcminute or 1/3600th of a degree.**

Such a system of measurement, based on the number 60, is called a **sexagesimal** system. We find a sexagesimal system far more difficult to use than a decimal system, but such a system did not daunt the Babylonians or the Egyptians and Greeks who also adopted this system. Unfortunately, it became so ingrained in early western civilization that it is still in common use for making angular measurements today. Thus we must learn to work with it. You should note that we also use a sexagesimal system for counting time. Often, we shall also want to express angular distance in decimal degrees. That is,  $5^{\circ} 15'$  in the sexagesimal system is equivalent to 5.25 degrees in the decimal system.

**PROBLEM 1:** Write 15.67 degrees in sexagesimal notation on the answer sheet.

Remember that astronomers find it useful to express the celestial coordinate, right ascension, in time units. This is because the Earth rotates eastward on its axis, once every day. This makes the celestial sphere appear to turn at the same rate, but in the opposite direction, namely, westward. That is, if one faces south, stars would appear to move from the east towards the west, which would be from your left to your right and is referred to as the **apparent diurnal rotation of the celestial sphere**.

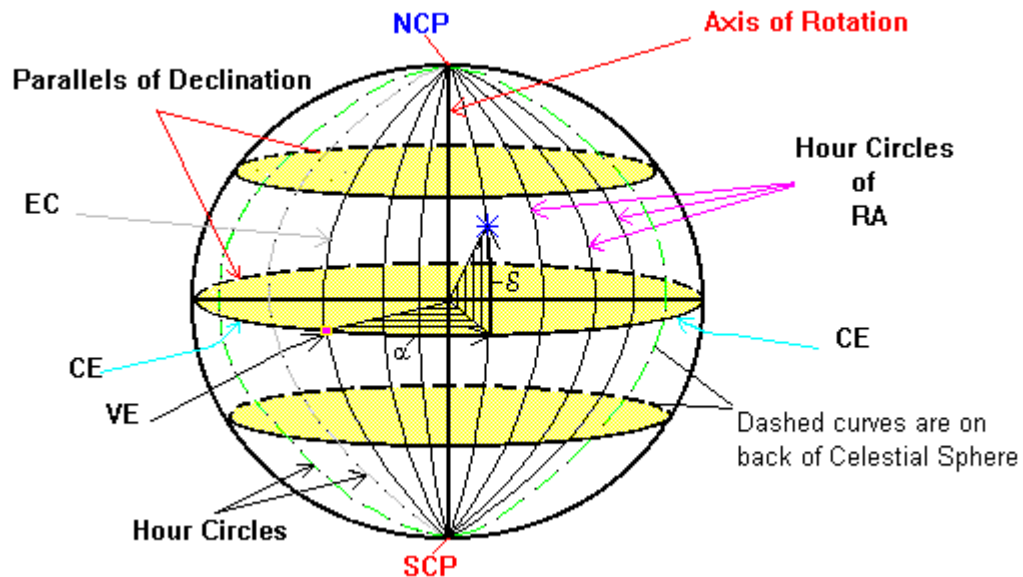
The rate of this motion is 15 degrees per hour. This number comes from the fact that Earth, or celestial sphere (you may assume one or the other rotates but not both), makes one complete turn through 360 degrees in 24 hours. This also means that the Earth rotates through an angle of 1 degree every four minutes of time. Since 1 degree contains 60', then the Earth turns 15' every 1m. This should point out the distinct difference between arcminutes and time minutes. One is an angle and the other is a time. **Never substitute one unit's abbreviation for the other, that is, never write 45' (forty-five arcminutes) when you mean 45m (forty-five minutes of time), or vice versa.**

**PROBLEM 2:** How much time does it take the Earth to rotate  $65^{\circ}$ ?

First record your answer in hours and decimal parts thereof. Then convert the decimal part of an hour into minutes and record the hours and minutes also, like this:  $7.33 \text{ hr.} = 7^{\text{h}} 20^{\text{m}}$ .

### III. Getting Acquainted with the Celestial Globe

Examine your celestial globe. The outer, transparent, plastic sphere represents the sky. Inside is a smaller sphere representing the Earth. A rod passes through the center of the Earth and extends outwards to touch the plastic sphere at two opposite points. This is the axis of rotation of the Earth or the Celestial sphere, depending on which you assume is rotating. The two points where the axis touches the celestial sphere are called the **north** and **south celestial poles**, **NCP** and **SCP**. Visually locate these two points on the globe. Also refer to the diagram below.



Midway between the poles is a great circle that divides the celestial sphere into two hemispheres. This circle is called the celestial equator (**CE**). Now find this circle on the globe and memorize the following definition.

**Celestial Equator: The great circle on the celestial sphere, every point of which is exactly 90 degrees from the celestial poles.**

There is a family of great circles that run from one celestial pole to the other and cross the celestial equator at a right angle. These are called hour circles of right ascension and they are analogous to meridians of longitude on the Earth. On the globe, hour circles of right ascension are drawn at regular intervals; these are considered to be fiducial circles, that is, they are circles indicating a precisely known value. Familiarize yourself with these circles on the globe now. Near the points where the hour circles cross the celestial equator, there should be a number that identifies the right ascension of that hour circle. Try to locate some of these.

**Question 3:** What is the interval, in hours, between the fiducial hour circles that are drawn and numbered on the globe? Write your answer on the answer sheet.

Remember that a point called the vernal equinox (**VE**) is the origin of our celestial coordinate system. This point is located on the celestial equator. Right ascension starts at the vernal equinox and increases eastward from there, all the way around the celestial sphere back to the vernal equinox again. That is, RA increases eastward from 0 to 24 hours. Hence, the number zero marks the hour circle passing through the vernal equinox. This hour circle is called the **equinoctial colure (EC)**. Now find this hour circle and the vernal equinox itself and make a mental note of where they are located on the globe.

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There is another family of circles, each member of which runs around the celestial sphere parallel to the celestial equator, anywhere between the latter and the celestial poles. These are called **parallels of declination** and are analogous to parallels of latitude on the Earth. All of these circles are smaller than the celestial equator and the closer one is to the celestial poles, the smaller it is. The celestial equator is itself a parallel of declination. See if you can locate these now. There should be a number written somewhere on each of these circles to identify what declination that circle represents.

**Question 4:** On the answer sheet, write the interval in degrees between the fiducial parallels of declination that are drawn on the globe.

Declination is an angle measured north or south from the celestial equator. This angle can be imagined as an arc drawn on the globe starting at the celestial equator and extending along an hour circle to the parallel of declination passing through the object we are trying to locate. Note and memorize the following:

**Right ascension ( $\alpha$ )** is the angular distance measured eastward around the sky from the vernal equinox.

**Declination ( $\delta$ )** is the angular distance measured north (+) or south (-) from the celestial equator.

**All objects located on the same parallel of declination have the same declination but different right ascensions. Similarly, all objects located on the same hour circle have the same right ascension but different declinations.**

## IV. Locating Objects on the Celestial Globe by Interpolation

In order to locate an object on the celestial sphere, remember the following rule:

**Through any object on the celestial sphere, one can draw a definite hour circle of right ascension and a definite parallel of declination.**

That is, the hour circles and declination parallels that are already drawn on the globe are referred to as **fiducial** ones, but they are not the only ones that could be drawn. Hence, if the parallel of declination passing through an object is not exactly one of the fiducial values, you will need to employ a technique called **interpolation** to determine the value of that object's declination,  $\delta$ . For example, if an object has a declination of  $17^{\circ} 30'$ , and the fiducial parallels of declination are drawn every  $10^{\circ}$  apart on some hypothetical globe (not necessarily your globe), you will need to know what fraction of the distance between the 10th and 20th parallels corresponds to this declination. The fractional distance from the 10th parallel towards the 20th parallel would be  $(17.50-10.00)/(20.0-10.0)$  or  $7.50/10.00=0.75$ , that is,  $3/4$ ths the distance. Notice that we have converted the sexagesimal value of  $17^{\circ} 30'$  to its decimal equivalent, 17.50 degrees, with 2 decimal place precision, for convenience in using a calculator. Now we use a flexible ruler and measure the distance between the 10th parallel and the 20th parallel. Suppose this number is 2.85cm. (the value on your globe is not this value). Therefore, the object is located a distance of  $2.85\text{cm} \times 0.75=2.14\text{cm}$  from the 10th parallel towards the 20th parallel. We now use our ruler to locate the position of the parallel of declination that passes through our object.

Similarly, if a star has  $RA=7^{\text{h}} 20^{\text{m}}$ , its hour circle is on third of the distance from the 7th hour circle to the 8th hour circle. This is because  $20^{\text{m}}$  is  $1/3$ rd (or 0.33) of an hour. We now proceed as

for declination and use a flexible ruler to measure the distance between hour circles. Unlike for declination, our result will depend on what declination circle we make this measurement. Let us say we choose to make this measurement along the celestial equator and that the result is 4.27cm. Then the hour circle passing through our object is located  $4.27\text{cm} \times 0.33 = 1.41\text{cm}$  from the 7th hour circle towards the 8th hour circle, and we measure this distance along the celestial equator. You should now know what to do if hour circles are not drawn on the globe for every hour.

## V. Assignment

### Part 1

Now locate and identify the objects, which have their coordinates listed on the answer sheet, and the constellations in which they are located. Stars are identified by lower case letters, whereas constellations are identified by upper case letters. Be careful not to confuse the two. With a few exceptions, stars that are in the same constellation are connected by lines. Note this.

Objects appearing like asterisks and identified by an upper case "M" followed by a number, such as, **M52**, are objects in Messier's Catalogue and are usually star clusters, nebulae, or galaxies. If one of the objects you identify is a Messier object, it is not necessary for you to know which kind of object it is, just write your answer to be the Messier designation, such as, **M101**. Don't forget, Messier objects, like stars, are located in a constellation.

Warning, the term "ECLIPTIC", the months of the year, and "PE" are also engraved on the globe and are not constellations and cannot be answers.

### Part 2

Search over the surface of the globe to find 3 other Messier objects. This is most readily done by visually scanning north to south within 1 hour bands of right ascension (RA) at a time. By visual interpolation, determine the RA and Dec. coordinates for these objects and record the results on the answer sheet using the proper format (RA= $7^{\text{h}} 20^{\text{m}}$  ; Dec. =  $-17^{\circ} 30'$ ). Do not use colons. Be as precise as you can. Do not look up the exact coordinates on line or in a reference, since those values will be somewhat different than what you will read from the celestial globe.

Now go online to <http://www.seds.org/messier/data2.html>. Then click on the link "messier index." Go down the list and identify the Messier objects as either a nebula, a galaxy, an open cluster, or a globular cluster, and fill in the blank on the answer page.

# ANSWER SHEET

## EQUATORIAL COORDINATES ON A GLOBE

### II. Angular Measurement

1. Sexagesimal equivalent of  $15.67^\circ$ : \_\_\_\_\_

2. Time for rotation of  $65^\circ$ : \_\_\_\_\_

### III. Getting Acquainted with the Celestial Globe

3. Spacing of reference hour circles drawn on the globe in hours: \_\_\_\_\_

4. Spacing of reference declination parallels drawn on the globe in degrees: \_\_\_\_\_

### V. Part 1: Identification of Objects on Celestial Globe

	RA	DEC	Object	Constellation
1.	4:36	+16:29	_____	_____
2.	5:14	-08:13	_____	_____
3.	5:15	+46:15	_____	_____
4.	5:33	-05:20	_____	_____
5.	6:45	-16:42	_____	_____
6.	7:39	+05:15	_____	_____
7.	7:42	+28:00	_____	_____
8.	14:16	+19:13	_____	_____
9.	16:27	-26:15	_____	_____
10.	16:42	+36:28	_____	_____
11.	18:35	+38:44	_____	_____
12.	19:50	+08:50	_____	_____

### V. Part 2: The Messier Catalog

For RA, use superscripts h for hours and m for minutes, not colons. For declination use degree symbols for superscripts and the symbol, ', for arcminutes. Do not use colons.

	RA	Dec.	Object	Constellation	Type of Object
1.	_____	_____	_____	_____	_____
2.	_____	_____	_____	_____	_____
3.	_____	_____	_____	_____	_____