When the world celebrated the start of the year 2000, on New Year’s Eve all eyes were on the small island of Tonga in the south Pacific, because this was the first place to experience the new year. Every day the sun rises first on Tonga, then Fiji, New Zealand and eastern Australia, so we experience a new day before the rest of the world. How is this possible?

To understand the reason, we must study the geometry and geography of the world and understand the way distances and times are measured on the Earth’s surface—and take into account the fact that the Earth is a sphere rather than a flat surface. As long ago as the 2nd century BC, the Greek astronomer Hipparchus developed a coordinate system for locating positions on the Earth using angles of latitude and longitude. This system is still used in air and sea navigation today, as is the imperial unit called the nautical mile for measuring and charting distances across the globe. We will learn more about Earth measurement in this chapter, including the use of standard time zones for places around the world.

In this chapter you will learn how to:
- understand and use the following geographical concepts: great and small circles, latitude and longitude, the Equator and the Greenwich meridian
- use latitude and longitude to locate positions on the Earth’s surface
- calculate arc lengths of a circle
- convert between nautical miles and kilometres
- calculate distances between two points on the same great circle, in nautical miles and kilometres
- understand the meaning of a knot as a measure of speed and use it to solve problems
- calculate time differences using differences in longitude
- use standard time zones and the International Date Line to solve problems involving travel, communication and daylight saving.
The following items are useful teaching and learning aids for understanding the Earth geometry concepts introduced in this chapter: world globe, atlas, orange and knife to cut it with, tennis ball, golf ball or basketball, black markers or rubber bands.

LATITUDE AND LONGITUDE

When describing the location of a point on a number plane or map, we use a coordinate system involving ordered pairs \((x, y)\).

Positions on the Earth’s surface also can be described by a coordinate system, one involving \textit{latitude} and \textit{longitude}. However, because the Earth is a sphere, we must use a special grid of lines that run across and down a sphere. The diagrams below illustrate this grid on a world globe (3D) and flat world map (2D).
Great and small circles

The Earth is a sphere. If you cut any ‘slice’ through a sphere, the shape of the slice is a circle. The circle can be of different sizes, ranging from very small (if you slice near the edge) to large (if you slice through the centre of the sphere). A slice that goes through the centre of a sphere is called a great circle, and its radius is the same as that of the sphere. Any other slice is called a small circle, because its radius is smaller than that of a great circle.

Parallels of latitude

Parallels of latitude are imaginary lines that run across and around the Earth. They are parallel circles of differing sizes. The main parallel of latitude is the Equator, which is a great circle labelled 0°. The other parallels of latitude are small circles either north or south of the Equator.

Half of a sphere is called a hemisphere, and the Equator divides the world into the northern and southern hemispheres.

The angle of latitude is the angle that a line from the centre of the Earth, \( O \), to a parallel of latitude makes with the Equator. The diagram illustrates the 50°N parallel of latitude.

Parallels of latitude range from 90°N to 90°S. 90°N is the North Pole, 90°S is the South Pole. Because they are the top and bottom ‘ends’ of the Earth, they are dots rather than circles.
**Meridians of longitude**

Meridians of longitude are imaginary lines that run down the Earth. They are great semicircles between the North and South Poles, so they are not parallel but look like lines on the segments (‘wedges’) of an orange. The main meridian of longitude is called the **Greenwich meridian** or **prime meridian**. It is 0° longitude and passes through the Royal Greenwich Observatory in London, UK. The other meridians of longitude are either east or west of the Greenwich meridian. The Greenwich meridian divides the world into the eastern and western hemispheres.

The **angle of longitude** is the angle a meridian of longitude makes with the Greenwich meridian—that is, the angle of the ‘wedge’. The diagram illustrates the 35°E meridian of longitude.

Meridians of longitude range from 180°W to 180°E. 180°W and 180°E are actually the same meridian, the line directly opposite the Greenwich meridian on the other side of the Earth. This is called the **International Date Line** and runs through the Pacific Ocean east of Fiji. At the poles, all meridians of longitude meet.

**Position coordinates**

Locations on the Earth are described using latitude (°N or °S) and longitude (°E or °W). For example, Canberra has coordinates (35°S, 149°E), meaning it is 35° south of the Equator and 149° east of the Greenwich meridian.
Example 1
Match the following coordinates to the points illustrated in the diagram of the Earth.

(a) (50°S, 55°E) (b) (30°N, 55°E)  
(c) (30°N, 0°)  (d) (75°N, 55°E)  
(e) (0°, 0°)  (f) (0°, 55°E)  
(g) (50°S, 0°)  (h) (75°N, 0°)

Solution
With the Greenwich meridian as illustrated, the meridian of longitude joining $Q$, $S$, $U$ and $W$ is 55°E.

(a) (50°S, 55°E) is point $W$  
(b) (30°N, 55°E) is point $S$  
(c) (30°N, 0°) is point $R$  
(d) (75°N, 55°E) is point $Q$  
(e) (0°, 0°) is point $T$  
(f) (0°, 55°E) is point $U$  
(g) (50°S, 0°) is point $V$  
(h) (75°N, 0°) is point $P$

Example 2
The coordinates of Sydney and Tokyo, Japan are (34°S, 151°E) and (35°N, 139°E) respectively.

(a) What is the difference in latitude between Sydney and Tokyo?  
(b) What is the difference in longitude between Sydney and Tokyo?  
(c) Which city is further west: Sydney or Tokyo?

Solution
It is useful to draw a grid like a number plane.

(a) Difference in latitude = $35° + 34° = 69°$  
(b) Difference in longitude = $151° - 139° = 12°$  
(c) Sydney (151°E) is further east than Tokyo (139°E), so Tokyo is further west (also seen on grid).

Example 3
Goulburn has coordinates (34°S, 149°E). Armidale is 4° north and 2° east of Goulburn. What are the coordinates of Armidale?
Solution

Latitude = 34°S − 4° = 30°S
Longitude = 149°E + 2° = 151°E
∴ Coordinates of Armidale are (30°S, 151°E).

Think: Latitude and longitude mnemonics

Can you think of some ways of remembering the difference between latitude and longitude? Here are some suggestions:

Exercise 7-01: Latitude and longitude

Equipment: An atlas and/or a world globe may be helpful in answering these questions.

1. Match the following coordinates to the points illustrated on the diagram of the Earth.
   (a) (0°, 100°E)    (b) (40°S, 60°E)
   (c) (60°N, 60°E)   (d) (0°, 60°E)
   (e) (15°S, 100°E)  (f) (60°N, 100°E)
   (g) (15°S, 60°E)   (h) (40°S, 100°E)
2. Match each of these cities with a letter on the map below.
   (a) Moscow (55°N, 37°E)  (b) Edinburgh (56°N, 3°W)
   (c) Athens (38°N, 23°E)  (d) San Francisco (38°N, 122°W)
   (e) Perth (32°S, 116°E)  (f) Beijing (40°N, 116°E)
   (g) Alexandria (31°N, 30°E)  (h) Tokyo (35°N, 139°E)
   (i) St Petersburg (60°N, 30°E)  (j) Johannesburg (26°S, 28°E)
   (k) Lima (12°S, 77°W)  (l) Hong Kong (22°N, 114°E)

3. Which city from question 2 is closest to:
   (a) the North Pole?  (b) the Equator?  (c) the Greenwich meridian?

4. Is Australia in:
   (a) the northern or southern hemisphere?  (b) the eastern or western hemisphere?

5. Write the coordinates of each of the points illustrated on the diagram of the Earth.
   (a) V  (b) T
   (c) U  (d) Z
   (e) R  (f) W
   (g) X  (h) S
   (i) Y

6. What can be found at the 90°S parallel of latitude?

7. Are these small circles or great circles?
   (a) the Equator  (b) the 30°N parallel  (c) the International Date Line
   (d) the 23°S parallel  (e) the Greenwich meridian  (f) the 145°W meridian

8. Calculate the difference in latitude between these cities, and state whether the second city listed is north or south of the first.
   (a) Shanghai, China (31°N, 121°E) and New York, USA (40°N, 64°W)
   (b) Nairobi, Kenya (1°S, 37°E) and Bangkok, Thailand (13°N, 100°E)
   (c) Moscow, Russia (55°N, 37°E) and London, UK (51°N, 0°)
   (d) Auckland, NZ (37°S, 174°E) and Canberra (35°S, 149°E)
   (e) Melbourne (37°S, 145°E) and Cairo, Egypt (30°N, 31°E)
   (f) Newcastle (33°S, 151°E) and West Wyalong (34°S, 147°E)

9. Deniliquin is 1° due south of Hay. If Hay’s coordinates are (34°S, 145°E), what are Deniliquin’s coordinates?
10. Calculate the difference in longitude between these cities, and state whether the second city listed is east or west of the first.
   (a) Budapest, Hungary (47°N, 19°E) and Miami, USA (25°N, 80°W)
   (b) Athens, Greece (38°N, 23°E) and Paris, France (49°N, 2°E)
   (c) Havana, Cuba (23°N, 82°W) and Mexico City, Mexico (19°N, 99°W)
   (d) Buenos Aires, Argentina (34°S, 58°W) and Johannesburg, South Africa (26°S, 28°E)
   (e) Manila, Philippines (14°N, 121°E) and Port Moresby, Papua New Guinea (9°S, 147°E)
   (f) Finley (35°S, 145°E) and Bourke (30°S, 146°E)

11. Broken Hill is 7° due west of Dubbo. If Dubbo’s position is (32°S, 148°E), what is Broken Hill’s position?

12. Ipswich is 2° north and 2° east of Moree, which has coordinates (29°S, 150°E). What are Ipswich’s coordinates?

13. Ballarat is 2° south and 6° west of Batemans Bay (35°S, 150°E). What are the coordinates of Ballarat?

14. Explain in your own words the difference between a small circle and a great circle.

15. Do Sydney and Tamworth lie on the same line of latitude or longitude?

16. Where on Earth is it possible to stand on every meridian of longitude?

**Investigation: Exploring an atlas and world globe**

Use an atlas and a world globe to explore the coordinate system of latitude and longitude. Locate the positions of different places around the world. Use an Australian atlas to locate Australian cities and towns. Some computers have a World Map tool in their system software (control panels), in which you enter the name of a city or click a point on a map and it outputs the coordinates of the location, the local time there and its distance from the last place entered.

1. Use a map or globe to estimate the position coordinates of these cities.
   (a) Washington, DC, USA  (b) Singapore  (c) Adelaide
   (d) Dublin, Ireland  (e) Lisbon, Portugal  (f) Moscow, Russia

2. Find the actual coordinates of the six cities above by looking up the index of an atlas.

3. List the six cities above in order from:
   (a) west to east  (b) north to south

4. What city is located at:
   (a) (19°N, 155°W)?  (b) (14°N, 121°E)?  (c) (34°S, 58°W)?
   (d) (42°N, 12°E)?  (e) (12°S, 131°E)?  (f) (42°N, 87°W)?

5. How does a flat map distort the positions and sizes of places with high latitudes?

6. Where does:
   (a) north become south?  (b) east become west?

7. Which way does the Earth spin? (Think of sunrise and sunset.)

8. Where is:
   (a) the Middle East?  (b) the Far East?  (c) Western civilisation?
   (d) the land ‘down under’?  (e) Ecuador?  (f) the West Indies?
SPECIAL CIRCLES OF LATITUDE

As the Earth orbits the Sun, it is always tilted at an angle of 23.5° to the plane of its orbit. When the tilt towards the Sun is greatest, the hemisphere nearer the Sun has its summer solstice (longest day of the year, most daylight hours) while the opposite hemisphere has its winter solstice (shortest day, least daylight hours). On that day, the Sun shines directly on the 23.5° circle of latitude, called the Tropic of Cancer in the northern hemisphere and the Tropic of Capricorn in the southern hemisphere. The diagrams illustrate the summer solstice in the southern hemisphere.

The region between the Tropic of Cancer and Tropic of Capricorn is called ‘the tropics’. Because the Sun is directly above this region, places here tend to be warm in winter and hot in summer.

When one hemisphere is tilted towards the Sun, the opposite pole (North or South Pole) and its surrounding circle of latitude receive hardly any sunlight. During summer in the southern hemisphere, the area around the North Pole within the Arctic Circle (66°32'N) stays in darkness for most of the day, while the area around the South Pole within the Antarctic Circle (66°32'S) has daylight for most of the day. The situations are reversed when the northern hemisphere has its summer.

1. What countries do the tropics of Cancer and Capricorn pass through?
2. What are the dates of the solstices in the southern hemisphere?
3. What are the equinoxes and when do they occur?

GREAT CIRCLE DISTANCES

Arc length of a circle

In chapter 2 we learned the formula for calculating the length of an arc of a circle.

\[ l = \frac{\theta}{360} \times 2\pi r \]

where \( \theta \) is the size of the central angle.
Example 4
A shotput circle has a radius of 1.05 m. Calculate the length of the arc $AB$ correct to 3 significant figures if it makes an angle of $40^\circ$ at the centre of the circle.

**Solution**

\[
\ell = \frac{\theta}{360} \times 2\pi r \\
= \frac{40}{360} \times 2\pi \times 1.05 \\
= 0.7330 \ldots \\
= 0.733 \text{ m}
\]

Shortest distance between two points on the Earth’s surface

On a flat surface, the shortest distance between two points $A$ and $B$ is a straight line. However, on the curved surface of a sphere, it is not possible to construct a straight line between $A$ and $B$. In this case, the shortest distance between the two points is the arc of the great circle that passes through those two points. This can be demonstrated using string on an orange, tennis ball or basketball.

The shortest distance between two points on the Earth’s surface is called the great circle distance. The angle made at the centre of the Earth by the two points is called their angular distance. We can use the arc length formula to calculate the shortest distance between the two points.

Example 5
The diagram shows two points $P$ and $Q$ on the Earth’s surface. The angular distance between them is $63^\circ$. Calculate the great circle distance between $P$ and $Q$, to the nearest kilometre, if the radius of the Earth is 6400 km.

**Solution**

\[
PQ = \frac{\theta}{360} \times 2\pi r \\
= \frac{63}{360} \times 2\pi \times 6400 \\
= 7037.1675 \ldots \\
= 7037 \text{ km}
\]

Example 6
Beijing, China and Perth have coordinates $(40^\circ\text{N}, 116^\circ\text{E})$ and $(32^\circ\text{S}, 116^\circ\text{E})$ respectively.

(a) What great circle joins Beijing and Perth?

(b) What is the angular distance between these two cities?

(c) Hence, calculate the shortest distance between Beijing and Perth, to the nearest kilometre, given that the Earth’s radius is 6400 km.
Solution
(a) Beijing and Perth both lie on the 116°E meridian of longitude, which is a great circle.
(b) Angular distance = 40° + 32° = 72°
(c) Distance = \( \frac{72}{360} \times 2\pi \times 6400 \)
= 8042.4772 \ldots
= 8042 km

The radius of the Earth is approximately 6400 km.

Small circle distances
Example 7
Moscow, Russia and Copenhagen, Denmark have coordinates (55°N, 38°E) and (55°N, 12°E) respectively.
(a) What special small circle passes through both cities?
(b) What is the angle between Moscow and Copenhagen at the centre of this small circle?
(c) If the radius of this small circle is 3652 km, use the arc length formula to calculate the small circle distance between Moscow and Copenhagen, to the nearest kilometre.

Solution
(a) Moscow and Copenhagen both lie on the 55°N parallel of latitude, which is a small circle.
(b) Angle at centre of small circle = 38° − 12° = 26°
(c) Small circle distance = \( \frac{26}{360} \times 2\pi \times 3652 \)
= 1657.2250 \ldots
= 1657 km

Note: The small circle distance is not the shortest distance between two places.

Technology: Locations on the Earth
Distance calculator websites
Use an Internet search engine to find one of the many ‘distance calculator’ websites available. This is a program that allows you to enter the names of two places on Earth, or their coordinates, and then it calculates the shortest (great circle) distance between them. Some computers have a distance calculator included in their systems software.

Global positioning system
A global positioning system (GPS) uses Earth satellites to calculate a person’s location on Earth. It is possible to purchase a hand-held device that uses GPS technology to calculate your position coordinates. Investigate how GPS works.
1. Use string to measure and calculate the shortest distance between two points on a world globe, using the globe’s scale. Compare this distance to the straight line distance on a flat map.

2. If a great circle path is drawn on a flat map, it appears as a curve. (Why?) Because of this, airline pilots and ship captains frequently need to change their bearings during their course to take the shortest route. Over long distances on the Earth, a straight line isn’t the shortest route.

Modelling activities: Great circle distances

What are the dangers in using a flat map to calculate distances and navigate the Earth?

Exercise 7-02: Great circle distances

In this exercise, assume that the radius of the Earth is 6400 km.

1. In each of these diagrams, calculate the arc length $l$ correct to 1 decimal place.
   
   (a) $5.6\ m$  
   
   (b) $108^\circ$  
   
   (c) $28\ m$  

2. The angular distance between points $P$ and $Q$ on the Earth’s surface is $166^\circ$. Calculate the arc length $PQ$, to the nearest kilometre.

3. (a) What great circle passes through points $C$ and $D$?
   (b) What is the angular distance between $C$ and $D$?
   (c) Calculate the shortest distance between $C$ and $D$, to the nearest kilometre
   (d) What great circle passes through points $A$ and $D$?
   (e) Calculate the great circle distance between $A$ and $D$, to the nearest kilometre.
   (f) What is the distance between points $B$ and $C$, to the nearest kilometre?
   (g) Is the $48^\circ$N parallel of latitude a small circle or great circle?
   (h) Calculate the distance between $A$ and $B$, to the nearest kilometre, if the radius of the circle that goes through them is 4260 km.
4. (a) What is the angle size turned by the minute hand of a clock in 20 minutes?
(b) Hence, calculate the distance travelled by the tip of the minute hand during this time if the minute hand is 18 cm long. Answer correct to 1 decimal place.

5. Paris, France has coordinates (49°N, 2°E). Calculate its distance (to the nearest kilometre) from:
   (a) the Equator
   (b) the North Pole

6. Melbourne (37°S, 145°E) and Cairns (17°S, 145°E) lie on the same meridian of longitude.
   (a) Is the 145°E meridian a great circle or small circle?
   (b) What is the size of the angle made by these two cities at the centre of this circle?
   (c) Calculate the shortest distance between Melbourne and Cairns, to the nearest kilometre.

   (a) Is the 32°S parallel a great circle or small circle?
   (b) What is the size of the angle made by these two cities at the centre of this circle?
   (c) Calculate, to the nearest kilometre, the distance between Perth and Taree along this circle if its radius is 5400 km.

8. The Antarctic Circle near the South Pole is the 66.5°S parallel of latitude. Calculate how many kilometres this circle is from:
   (a) the Equator
   (b) the South Pole

9. The Tropic of Capricorn is the 23.5°S parallel of latitude. Calculate how many kilometres this circle is from:
   (a) the North Pole
   (b) the Antarctic Circle

10. Calculate, to the nearest kilometre, the great circle distances between these cities.
    (a) Osaka, Japan (34°N, 135°E) and Alice Springs (23°S, 135°E)
    (b) Pretoria, South Africa (25°S, 28°E) and Minsk, Belorussia (54°N, 28°E)
    (c) Kampala, Uganda (0°, 32°E) and Macapa, Brazil (0°, 51°W)
    (d) Mawson, Antarctica (67°S, 63°E) and Chelyabinsk, Russia (54°N, 63°E)
    (e) Port Moresby, Papua New Guinea (9°S, 147°E) and Nyngan (31°S, 147°E)
    (f) Geelong (38°S, 144°E) and Ivanhoe (33°S, 144°E)
    (g) Leeton (34°S, 146°E) and Townsville (19°S, 146°E)

11. Durban, South Africa has coordinates (30°S, 31°E) while Grafton has coordinates (30°S, 153°E). If the radius of the 30°S parallel of latitude is 5515 km, calculate the distance between Durban and Grafton along this parallel, to the nearest kilometre.

12. If you dug a hole from Beijing, China (40°N, 116°N) through the centre of the Earth and came out on the other side, you would end up at point X, somewhere in Argentina.
    (a) What would be the coordinates of the point X?
    (b) How many kilometres are there between Beijing and point X:
        (i) in a straight line through the Earth’s centre?
        (ii) in a great circle along the Earth’s surface?

13. The great circle distance between Sydney and Honolulu, Hawaii is 4170 km. What angle is made at the centre of the Earth by these two cities? Answer to the nearest degree.

14. It is possible to fly from Perth (32°S, 115°E) to Tierra del Fuego (54°S, 65°W) on the southern tip of South America by going directly over the South Pole along a line of longitude. Calculate the great circle distance between Perth and Tierra del Fuego, to the nearest kilometre.
The radius of a circle of latitude can be calculated using trigonometry—in particular, using the cosine ratio in a right-angled triangle.

In the diagram, the $50^\circ$N circle of latitude is shown. Let its radius be $r$.

$OR = 6367$ km is the radius of the Earth, to the nearest kilometre.

1. Explain why $\angle TOR = 50^\circ$.
2. Explain why $\angle PTO = 50^\circ$.
3. Explain why $OT = 6367$ km.
4. Hence, prove that $r = 6367 \cos 50^\circ$ and calculate its value to the nearest kilometre.
5. Find a similar expression to calculate the radius of the $78^\circ$S circle of latitude.
6. What should happen to the radius, $r$, of a circle of latitude as the angle of latitude gets larger (and closer to $90^\circ$)? Verify this.

**NAUTICAL MILES AND KNOTS**

**Nautical miles**

For sea and air travel, the nautical mile (abbreviated M or nM) is used instead of kilometres. It has been used for centuries by sailors and navigators because it is directly related to the latitude–longitude system. A distance of 1 nautical mile (1 M) on the Earth’s surface is equivalent to an angle of 1 minute ($\frac{1}{60}$ of a degree) on a great circle of the Earth. Put another way, 60 nautical miles (60 M) are equivalent to an angle of 1 degree on a great circle.

We can convert 1 nautical mile to kilometres using the arc length formula,

$$l = \frac{\theta}{360} \times 2\pi r$$

with $\theta = \frac{1}{60}^\circ$ and $r = 6367.4$ km (a more accurate measure of the Earth’s radius).

$$1 \text{ M} = \frac{\frac{1}{60}}{360} \times 2\pi \times 6367.4$$

$$= 1.8522 \ldots$$

$$= 1.852 \text{ km}$$

For many years, Britain and the USA used slightly different values for the size of a nautical mile, but the international nautical mile has now been defined to be exactly 1.852 km.

$1^\circ = 60 \text{ M on a great circle}$
$1 \text{ M} = 1.852 \text{ km}$
Example 8
(a) The distance between Port Macquarie and Lord Howe Island is 351 M. What is this
distance to the nearest kilometre?
(b) The distance between Hobart and the South Pole is 5280 km. What is this distance to the
nearest nautical mile?

Solution
(a) Distance between Port Macquarie and Lord Howe Island = $351 \times 1.852$
    = 650.052 km
    $\approx 650$ km
(b) Distance between Hobart and the South Pole = $5280 \div 1.852$
    = 2850.9719 … $\approx 2851$ M

Knots
Nautical and air speed is measured in knots, where 1 knot is 1 nautical mile per hour.

1 knot = 1 nautical mile/hour or 1 M/h
      = 1.852 km/h

Example 9
Between 10 am and 10 pm, a ship sailed 513 M. Calculate its average speed:
(a) in knots   (b) in km/h

Solution
(a) Time between 10 am and 10 pm = 12 hours
   Speed = $\frac{distance}{time}$ = $\frac{513}{12}$
   = 42.75 knots
(b) Speed = $42.75 \times 1.852$
   = 79.173 km/h

Example 10
Calculate:
(a) the distance between points $C$ and $D$ in nautical miles
(b) the distance between points $B$ and $D$ in kilometres
(c) the time it will take a plane to fly from $D$ to $B$ at an
    average speed of 650 knots

Solution
(a) $C$ and $D$ lie on a great circle, the Equator.
   Angular distance = 85°
   Distance $CD$ = $85 \times 60$ M
   = 5100 M
(b) $B$ and $D$ lie on a great circle, the 85°E meridian of longitude.
   Angular distance = 52°
   Distance $BD$ = $52 \times 60$
   = 3120 M
   = 3120 \times 1.852$ km
   = 5778.24 km
(c) Speed = \frac{\text{distance}}{\text{time}}

\[ 650 = \frac{3120}{t} \]

Use distance = 3120 M because speed is given in knots.

\[ 650t = 3120 \]

\[ t = \frac{3120}{650} = 4.8 \text{ hours (or 4 hours 48 minutes)} \]

Note: Using 1° = 60 M and 1 M = 1.852 km to calculate great circle distances is more accurate than using the arc length formula \( l = \frac{\theta}{360} \times 2\pi r \) with \( r = 6400 \) km, because it involves a more accurate measurement for the Earth’s radius (6367.4 km).

Exercise 7-03: Nautical miles and knots

1. Convert these distances to kilometres.
   (a) 750 M (b) 165 M (c) 444 M

2. A yacht sails between two islands in the Pacific Ocean: Norfolk Island (29°S, 168°E) and Vanuatu (17°S, 168°E).
   (a) What is the direction of Vanuatu from Norfolk Island?
   (b) Calculate the length of the yacht’s journey in nautical miles.
   (c) How long will the journey take if the yacht is sailing at an average speed of 8 knots?
      Answer in days and hours.

3. Convert these distances to nautical miles, correct to 1 decimal place.
   (a) 100 km (b) 254 km (c) 671 km

4. A plane flies along the 68°S parallel of latitude. How many nautical miles is it from:
   (a) the South Pole? (b) the North Pole? (c) the Equator?

5. (a) What is the circumference of the Earth in:
      (i) nautical miles? (ii) kilometres?
   (b) If a plane travels at an average speed of 440 knots, how long would it take to circle the Earth? Answer in days and hours.

6. Convert these speeds to kilometres per hour.
   (a) 77 knots (b) 25 knots (c) 390 knots

7. Calculate the following lengths in nautical miles.
   (a) \( WY \) (b) \( WX \) (c) \( XZ \)

8. The small circle that runs through points \( Y \) and \( Z \) in the diagram in question 7 has a radius of 1648 km.
   (a) Calculate the small circle distance between \( Y \) and \( Z \) using the arc length formula
      \[ l = \frac{\theta}{360} \times 2\pi r \] (correct to 2 decimal places).
   (b) Convert this distance to nautical miles (correct to 2 decimal places).
9. If a ship travels 315 nautical miles between 8 am and 6:30 pm in one day, calculate its average speed:
   (a) in knots
   (b) in km/h

10. Convert 1° on a great circle to kilometres.

11. A plane flew due north from Hobart at a speed of 330 knots for $5\frac{1}{4}$ hours.
    (a) How far did it travel in nautical miles?
    (b) How far did it travel in kilometres?
    (c) What is its current position if the coordinates of Hobart are (43°S, 147°E)? Answer to the nearest degree.

12. Calculate in nautical miles the great circle distances between these cities.
    (a) Darwin (12°S, 130°E) and Vladivostok, Russia (43°N, 130°E)
    (b) Toronto, Canada (43°N, 79°W) and Panama City, Panama (9°S, 79°W)
    (c) Singapore (0°, 103°E) and Quito, Ecuador (0°, 78°W)
    (d) Madrid, Spain (40°N, 3°W) and Abidjan, Ivory Coast (5°N, 3°W)
    (e) Hanoi, Vietnam (21°N, 106°E) and Ulan Bator, Mongolia (48°N, 106°E)
    (f) Mt Isa (20°S, 138°E) and Adelaide (35°S, 138°E)
    (g) Bourke (30°S, 146°E) and Townsville (19°S, 146°E)

13. A yacht is sailing due south from Sydney in the Sydney-to-Hobart Yacht Race. What is its position after travelling 8 hours at a speed of 16 knots if Sydney’s coordinates are (34°S, 151°E)? Answer to the nearest degree.

14. A cruise ship travels 174 km at an average speed of 28 knots.
    (a) Convert 174 km to nautical miles, correct to 2 decimal places.
    (b) How long will it take the ship to travel this distance? Answer in hours and minutes.

15. Boston, USA (42°N, 71°W) and Santiago, Chile (33°S, 71°W) are on the same meridian of longitude.
    (a) What is the direction of Boston from Santiago?
    (b) Calculate the distance between Boston and Santiago, to the nearest kilometre.

16. An aeroplane is flying south along the Greenwich meridian.
    (a) How many nautical miles will it cover after travelling 16° of latitude?
    (b) What was its speed in knots if it took $1\frac{3}{4}$ hours to cover this distance? Answer correct to 1 decimal place.

17. The world record for water speed is 250.7 knots, achieved in 1977 at Blowering Lake Dam, Tumut by Ken Warby in his hydroplane, *Spirit of Australia*. Calculate, correct to 4 significant figures:
    (a) the distance that can be travelled at this speed in 30 seconds, in nautical miles
    (b) the same distance in kilometres
    (c) 250.7 knots in km/h

18. A ship sailed east along the Equator for 427 nautical miles.
    (a) How many whole degrees of longitude were travelled during this time?
    (b) How long did this journey take if the ship averaged 14 knots?
Two points directly opposite each other on the Earth’s surface are called antipodes (pronounced ‘an-tip-po-dees’). They are the furthest distance apart that two points on Earth can be from each other. The Australia–New Zealand region is sometimes nicknamed ‘the Antipodes’ by the British because we are on the opposite side of the world to them. But are we exactly?

1. London has coordinates (51°N, 0°). What are the coordinates of the point X directly on the other side of the world?
2. Sydney has coordinates (34°S, 151°E). In what direction is point X from Sydney: NE, NW, SE or SW?
3. What is the difference in latitude and longitude between Sydney and point X?
4. Find point X in an atlas or on a world globe. What is the name of the islands that are actually there?

LONGITUDE AND TIME DIFFERENCES

As the Earth spins during the day, the Sun shines on a different part of it. The Earth makes a complete revolution (360°) every 24 hours.

Idea: Day/night simulation

Spin a world globe (or a basketball with line markings) and use a flashlight to demonstrate different parts of the world experiencing day and night over a 24-hour period.
When the Sun shines directly on a meridian of longitude, it is 12 noon at all places along that meridian. The Sun is directly overhead. The word *meridian* means ‘midday’ in Latin, and *ante meridiem* (am) means ‘before midday’ and *post meridiem* (pm) means ‘after midday’. When it is midday along a meridian, it is midnight along the opposite meridian (on the other side of the world).

Since the Earth spins 360° in 24 hours, it will turn 15° in 1 hour. Therefore, there should be 1 hour’s difference in local time per 15° of longitude, or 4 minutes’ difference per 1° of longitude.

15° longitude = 1 hour’s time difference
1° longitude = 4 minutes’ time difference

Around the world, local times are measured relative to the time along the Greenwich meridian 0°, called **Greenwich Mean Time (GMT)**, or **Universal Time (UT)**. Places east of the Greenwich meridian are *ahead* of GMT, while places west of the Greenwich meridian are *behind* GMT.

**Example 11**

In Vietnam, the local time is 7 hours ahead of GMT.
(a) What is the time in Vietnam when it is 11 am in London (GMT)?
(b) What meridian of longitude passes through Vietnam?
Solution
(a) 11 am + 7 hours = 6 pm The local time in Vietnam is 6 pm.
(b) 7 hours’ time difference = 7 \times 15° = 105° difference in longitude. Since London (GMT) is at 0° and Vietnam is ahead of GMT, the meridian of longitude passing through Vietnam is 105°E.

Example 12
In New York (east coast USA), the local time is 5 hours behind GMT.
(a) What is the time in New York when the (24-hour) time in London is 1500?
(b) What meridian of longitude passes through New York?

Solution
(a) 1500 – 5 hours = 1000. The local time in New York is 1000 (10 am).
(b) 5 hours’ time difference = 5 \times 15° = 75° difference in longitude. Since New York is behind GMT, the meridian of longitude passing through New York is 75°W.

Example 13
In Los Angeles, USA (119°W), a tennis match is played at 2 pm on Tuesday. The match is televised live to Sydney (151°E). What is the time in Sydney when this match is played?

Solution
Difference in longitude = 119° + 151° = 270°
Time difference = \frac{270}{15} = 18 hours
As Sydney is east of GMT and Los Angeles is west of GMT, Sydney time must be ahead of Los Angeles time.
Sydney time = 2 pm Tuesday + 18 hours = 8 am Wednesday

Example 14
When it is 9 pm in Bombay, India (19°N, 73°E), what is the local time in Jakarta, Indonesia (6°S, 106°E)?

Solution
Difference in longitude = 106° – 73° = 33°
Time difference = \frac{33}{15} = 2 \frac{1}{5} \text{ hours}
= 2 \text{ h } 12 \text{ min}
or Time difference = 33 \times 4 \text{ minutes}
= 132 \text{ minutes}
= 2 \frac{12}{60} \text{ hours}
= 2 \text{ h } 12 \text{ min}
Jakarta is east of Bombay, so its time is ahead of Bombay’s.
Local time in Jakarta = 9 pm + 2 h 12 min
= 11:12 pm
The unreality of ‘local time’

In Example 14, the time in Jakarta will not really be 11:12 pm because, as we shall see in the next part of this chapter, the world is divided into standard time zones. Jakarta is probably in a time zone where the time is 11:00 pm or 11:30 pm.

However, in the following exercise we shall ignore time zones and calculate ‘local times’ correct to the nearest minute.

Exercise 7-04: Longitude and time differences

1. Convert these times to 24-hour time.
   (a) 6:10 pm  (b) 8:46 pm  (c) 8:46 am
   (d) 3:47 pm  (e) 12:30 am  (f) 11:15 pm

2. Convert these times to 12-hour (am/pm) time.
   (a) 1600  (b) 0530  (c) 2140
   (d) 0035  (e) 1905  (f) 1450

3. What is the time:
   (a) 7 hours after 7 pm?  (b) 10 hours after 9 am?
   (c) 8 hours before 2 pm?  (d) 6.5 hours before 8 pm?
   (e) 2.5 hours after 0300?  (f) 15 hours before 0030?
   (g) 11 h 18 min after 1315?  (h) 7 h 36 min before 1420?

4. The time in Tahiti is 10 hours behind GMT.
   (a) What is the longitude of Tahiti?
   (b) What is the time in Greenwich (GMT) when it is 6:30 am in Tahiti?
   (c) What is the time in Tahiti when it is 6:30 am in Greenwich?

5. Kalgoorlie has coordinates (30°S, 121°E) while the Pacific island of Nauru has coordinates (0°, 166°E).
   (a) Calculate the difference in longitude between the two places.
   (b) Calculate the time difference between the two places.
   (c) What is the time in Nauru when it is 9:45 am in Kalgoorlie?

6. Hanoi, Vietnam lies on the 105°E meridian while Sydney lies on the 150°E meridian. When the time in Hanoi is 1730, what is the time in:
   (a) Sydney?
   (b) London (GMT)?

7. The time in Vienna, Austria (48°N, 16°E) is 3 hours before the time in Tehran, Iran.
   (a) Calculate the difference in longitude between the two cities.
   (b) Hence, what meridian of longitude goes through Tehran?
   (c) When it is 2315 in Tehran, what is the time in Vienna? Answer in 12-hour (am/pm) time.

8. Use the key on your calculator to convert these times to hours and minutes.
   (a) 22.7 hours  (b) 6.3 hours  (c) 4.9 hours
   (d) 18.4 hours  (e) 10.1 hours  (f) 15.6 hours

9. Convert these times to hours and minutes.
   (a) 482 minutes  (b) 271 minutes  (c) 350 minutes
   (d) 196 minutes  (e) 709 minutes  (f) 1214 minutes
10. (a) Calculate the difference in longitude between New Delhi, India (28°N, 77°E) and Milan, Italy (41°N, 12°E).
(b) Calculate the time difference between New Delhi and Milan in hours and minutes.
(c) What is the local time in Milan when it is 5 pm in New Delhi?

11. (a) Calculate the time difference between Lisbon, Portugal (38°N, 9°W) and Taipei, Taiwan (25°N, 121°E).
(b) What is the local time in Taipei when it is 1610 in Lisbon?

12. How many hours and minutes are there from:
   (a) 6:30 am to 9:30 pm?
   (b) 4:30 pm to midnight?
   (c) 3 am to 3 pm?
   (d) 10 am to 5:20 pm?
   (e) 8:30 am to 7:46 pm?
   (f) 4 am to 1:30 am?

13. Early navigators used local times (calculated from the position of the Sun) to determine their longitude position. Across what meridian of longitude is a ship sailing if its local time is 6:30 am and GMT shows 11:30 am?

14. An ocean liner’s local time is 5:45 pm when GMT is 8:05 am. What is its longitude position?

15. Houston, USA has coordinates (29°N, 95°W) while Kabul, Afghanistan has coordinates (34°N, 70°E). If it is 6:20 pm Sunday in Houston, what is the time in Kabul?

16. Guatemala is 6 hours behind GMT.
   (a) What meridian of longitude runs through Guatemala?
   (b) What is the time in Britain when it is 1:30 pm in Guatemala?

17. (a) When it is 7:30 pm Monday in Los Angeles, USA (34°N, 119°W), what is the time in Sydney (34°S, 151°E)?
   (b) A plane leaves Los Angeles at 7:30 pm Monday and flies $14\frac{1}{2}$ hours to get to Sydney. What is the local time in Sydney when it arrives?

18. Omsk, Russia and Lord Howe Island, in the Tasman Sea have coordinates (55°N, 73°E) and (31°S, 159°E) respectively. What is the local time in Omsk when it is 8:30 am on Lord Howe Island?

19. It is 1430 local time in Alice Springs. What is GMT given that Alice Springs has longitude 134°E?

20. A ship’s clock shows 1 pm when GMT shows 8 am. What is the longitude position of the ship?

21. What is the local time in Pretoria, South Africa (25°S, 30°E) when it is 2030 in London, UK?

22. What is the time in London, UK when the local time in Rio de Janeiro, Brazil (23°S, 43°W) is 1940?

23. (a) Calculate the time difference between Guangzhou, China (23°N, 113°E) and Gosford (33°S, 151°E).
   (b) If it is midday Saturday in Gosford, what is the local time in Guangzhou?

24. What is the local time in the Falkland Islands, in the South Atlantic (52°S, 60°W) when it is 8:30 pm Wednesday in Auckland, NZ (37°S, 174°E)?
INTERNATIONAL TIME ZONES

Although the Earth spins 1° every 4 minutes, it would be impractical to change the local time 4 minutes for every 1° change in longitude (approximately 111 km at the Equator). Since 1884, the Earth has been divided into standard time zones.

The map below shows the time zones, with roughly 1 hour difference per 15° of longitude. For example, places along the 105°E meridian (column S) are 7 hours ahead of GMT, while places along the 150°W meridian (column B) are 10 hours behind GMT. Some countries have made slight variations to these zones for geographical and administrative reasons. For example, Central Australian Time is actually 9.5 hours ahead of GMT instead of 9 hours, and New Zealand uses only one time zone (GMT +12) although it stretches across two (GMT +11 and GMT +12).

The International Date Line

On the opposite side of the Earth to the Greenwich meridian is the 180° meridian, where the eastern hemisphere meets the western hemisphere. This imaginary line is called the International Date Line (IDL), running vertically through the middle of the Pacific Ocean, between Fiji and Hawaii.

The IDL runs between the time zone that is 12 hours ahead of GMT, including New Zealand, Fiji and Nauru, and the time zone 11 hours behind GMT, including Samoa and Niue Island. So if you travel east and cross the IDL, east becomes west and today becomes yesterday (e.g. Wednesday becomes Tuesday) and you have the same day twice. The reverse occurs when you cross the IDL in the opposite direction, travelling west: today becomes tomorrow (e.g. Sunday becomes Monday) and you ‘lose’ a day.

Table of standard time zones

The table on the next page illustrates the international time zones relative to GMT and Australian Eastern Standard Time (AEST). AEST is the time zone for Queensland, NSW, ACT, Victoria and Tasmania. Time zone information for different countries can also be found at the back of the White Pages telephone directory.
<table>
<thead>
<tr>
<th>Hours from GMT</th>
<th>Hours from AEST</th>
<th>Places in this zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>−11</td>
<td>−21</td>
<td>Samoa, Niue Island, Midway Island</td>
</tr>
<tr>
<td>−10</td>
<td>−20</td>
<td>Hawai‘i, Cook Islands, Tahiti</td>
</tr>
<tr>
<td>−9</td>
<td>−19</td>
<td>Alaska</td>
</tr>
<tr>
<td>−8</td>
<td>−18</td>
<td>USA/Canada Pacific time (west coast)</td>
</tr>
<tr>
<td>−7</td>
<td>−17</td>
<td>USA/Canada Mountain time, Mexico (west)</td>
</tr>
<tr>
<td>−6</td>
<td>−16</td>
<td>USA/Canada Central time (mid-west), Mexico (east), El Salvador, Nicaragua</td>
</tr>
<tr>
<td>−5</td>
<td>−15</td>
<td>USA/Canada Eastern time (east coast), Cuba, Peru</td>
</tr>
<tr>
<td>−4</td>
<td>−14</td>
<td>Canada Atlantic time, Chile, Barbados, Venezuela, Brazil (west)</td>
</tr>
<tr>
<td>−3</td>
<td>−13</td>
<td>Argentina, Brazil (east), Uruguay, Greenland</td>
</tr>
<tr>
<td>−2</td>
<td>−12</td>
<td>South Sandwich Islands</td>
</tr>
<tr>
<td>−1</td>
<td>−11</td>
<td>Azores</td>
</tr>
<tr>
<td>0</td>
<td>−10</td>
<td>UK, Ireland, Iceland, Portugal, Ghana</td>
</tr>
<tr>
<td>+1</td>
<td>−9</td>
<td>Most of Europe, Algeria, Libya, Angola</td>
</tr>
<tr>
<td>+2</td>
<td>−8</td>
<td>Finland, Greece, Lebanon, Egypt, South Africa</td>
</tr>
<tr>
<td>+3</td>
<td>−7</td>
<td>Russia (west), Saudi Arabia, Kenya, Madagascar</td>
</tr>
<tr>
<td>+3.5</td>
<td>−6.5</td>
<td>Iran</td>
</tr>
<tr>
<td>+4</td>
<td>−6</td>
<td>Mauritius, United Arab Emirates</td>
</tr>
<tr>
<td>+4.5</td>
<td>−5.5</td>
<td>Afghanistan</td>
</tr>
<tr>
<td>+5</td>
<td>−5</td>
<td>Pakistan</td>
</tr>
<tr>
<td>+5.5</td>
<td>−4.5</td>
<td>India, Sri Lanka</td>
</tr>
<tr>
<td>+6</td>
<td>−4</td>
<td>Bangladesh</td>
</tr>
<tr>
<td>+6.5</td>
<td>−3.5</td>
<td>Myanmar (Burma), Cocos Islands</td>
</tr>
<tr>
<td>+7</td>
<td>−3</td>
<td>Vietnam, Cambodia, Thailand, Indonesia (west)</td>
</tr>
<tr>
<td>+8</td>
<td>−2</td>
<td>Australian Western Standard Time (WA), Malaysia, China, the Philippines</td>
</tr>
<tr>
<td>+9</td>
<td>−1</td>
<td>Japan, North Korea, South Korea, Indonesia (east)</td>
</tr>
<tr>
<td>+9.5</td>
<td>−0.5</td>
<td>Australian Central Standard Time (NT, SA, Broken Hill)</td>
</tr>
<tr>
<td>+10</td>
<td>0</td>
<td>Australian Eastern Standard Time, Papua New Guinea, Micronesia</td>
</tr>
<tr>
<td>+10.5</td>
<td>+0.5</td>
<td>Lord Howe Island</td>
</tr>
<tr>
<td>+11</td>
<td>+1</td>
<td>Vanuatu, New Caledonia, Solomon Islands</td>
</tr>
<tr>
<td>+11.5</td>
<td>+1.5</td>
<td>Norfolk Island</td>
</tr>
<tr>
<td>+12</td>
<td>+2</td>
<td>New Zealand, Fiji, Nauru, Siberia (east)</td>
</tr>
<tr>
<td>+13</td>
<td>+3</td>
<td>Tonga</td>
</tr>
</tbody>
</table>
Example 15
Chicago, USA is 6 hours behind GMT while Adelaide is 9.5 hours ahead of GMT. Calculate the local times in London, UK and Adelaide when it is 3:30 pm Tuesday in Chicago.

Solution

Chicago London Adelaide
-6 0 (GMT) +9.5

London time = 3:30 pm Tuesday + 6 hours
= 9:30 pm Tuesday
Adelaide time = 9:30 pm Tuesday + 9.5 hours (or 3:30 pm Tuesday + 15.5 hours)
= 7:00 am Wednesday

Example 16
A cricket match being played in Sri Lanka is telecast live to Australia and the UK. It is watched by a Sydney audience at 4:00 pm Sunday, AEST. Given that Sri Lankan time is GMT + 5.5 hours and AEST is GMT + 10 hours, at what time is the match being seen in:
(a) Sri Lanka? (b) the UK?

Solution

UK Sri Lanka Sydney
0 (GMT) +5.5 +10 (AEST)

(a) Sri Lankan time is 10 – 5.5 = 4.5 hours behind AEST.
Sri Lankan time = 4:00 pm Sunday – 4.5 hours
= 11:30 am Sunday

(b) UK time (GMT) is 10 hours behind AEST.
UK time = 4:00 pm Sunday – 10 hours
= 6:00 am Sunday
Or UK time is 5.5 hours behind Sri Lankan time.
UK time = 11:30 am Sunday – 5.5 hours
= 6:00 am Sunday

Example 17
Habib is flying from New York, USA to Istanbul, Turkey to visit his grandfather. New York is 5 hours behind GMT while Turkey is 2 hours ahead of GMT.
(a) Habib wants to call his grandfather on the phone before he leaves New York. At what time should he call so that it is 6 pm in Turkey?
(b) He boards the plane at 1:45 pm New York time and the trip lasts 8.5 hours. What is the local time in Istanbul when he arrives?

Solution

New York Istanbul
-5 0 (GMT) +2

(a) Time difference = 5 + 2 = 7 hours. New York is 7 hours behind Istanbul.
When it is 6 pm in Istanbul, the time in New York is 6 pm – 7 hours = 11 am.
Habib should call his grandfather at 11 am. New York time.
(b) Plane departs at 1:45 pm New York time and flies for 8.5 hours.
End of journey = 1:45 pm + 8.5 hours = 10:15 pm New York time
Istanbul time = 10:15 pm + 7 hours = 5:15 am (next day)
Daylight saving
In the warmer months of each year, many countries in the world adopt **daylight saving time** or **summer time** and turn their clocks forward 1 hour to take advantage of the increased hours of sunlight during this season. By ‘losing’ that hour at the start of daylight saving, people are actually working and sleeping 1 hour earlier and gaining maximum use of the daylight. The aims of daylight saving are to create savings on energy costs, to provide more recreation time for people, and to reduce crime and accidents.

Daylight saving has been operating in Australia since 1971, although Queensland, Western Australia and the Northern Territory do not participate in the scheme. In NSW, ACT, Victoria and South Australia (but not Tasmania), daylight saving runs from the last Sunday in October (mid spring) to the last Sunday in March (early autumn).

**Example 18**
Simone, in Melbourne, wants to use the Internet to chat with her cousin, Zac, in Vancouver, Canada. Canadian Pacific Standard Time is 8 hours behind GMT while Melbourne is 10 hours ahead of GMT. Also, daylight saving is operating in Canada. When should Simone log onto the Internet, to reach Zac when it is 4 pm Friday in Vancouver?

**Solution**
If daylight saving is operating in Canada, the time there is 1 hour ahead of normal—that is, 7 hours behind GMT.

Time difference = 7 + 10 = 17 hours. Melbourne is 17 hours ahead of Vancouver.

Log-on time = 4 pm Friday + 17 hours = 9 am Saturday.

Simone should log on at 9 am Saturday.

**Exercise 7-05: International time zones**

*Refer to the table on page 268 for this exercise.*

1. When it is 4 pm in Sydney, what is the time (and day if appropriate) in:
   (a) India?  
   (b) Russia (west)?  
   (c) New Caledonia?  
   (d) Greece?  
   (e) Hong Kong, China?  
   (f) San Francisco, USA (Pacific time)?

2. When it is 4 pm in London, UK, what is the time (and day if appropriate) in:
   (a) Greenland?  
   (b) Papua New Guinea?  
   (c) Montreal, Canada (Eastern time)?  
   (d) Nicaragua?  
   (e) Bosnia (Europe)?  
   (f) Myanmar?

3. What is the time difference between:
   (a) Malaysia and New Zealand?  
   (b) Brazil (east) and Chile?  
   (c) Iceland and the Philippines?  
   (d) Algeria and Salt Lake City, USA (Mountain time)

4. (a) What are the names of the three time zones in Australia?
    (b) Why do you think Broken Hill does not go by NSW time?

5. If the time in Sydney is 6 pm, what is the time in:
   (a) Melbourne?  
   (b) Hobart?  
   (c) Alice Springs?  
   (d) Perth?  
   (e) Adelaide?  
   (f) Surfers Paradise?
6. Queensland, Northern Territory and Western Australia do not participate in daylight saving. If the daylight-saving time in Sydney is 10:30 am, what is the time in:
   (a) Melbourne?    (b) Hobart?    (c) Alice Springs?
   (d) Perth?        (e) Adelaide?   (f) Surfers Paradise?

7. Does the sun rise earlier in Sydney or in Melbourne?

8. Name a place that is halfway between GMT and AEST.

9. Why is most of the world behind Australian Eastern Standard Time?

10. It takes \( \frac{8}{2} \) hours for a plane to fly from Sydney to Hawaii. If Heath leaves Sydney at 1:30 pm Friday, what will be the local time when he arrives in Hawaii?

11. (a) What is the time in Santiago, Chile when it is 12 noon in Perth?
    (b) What does this say about the positions of Perth and Santiago on the world globe?

12. The Australian Open Tennis competition is broadcast live from Melbourne at 8:30 pm local time. At what time is this seen in:
    (a) Dallas, USA (Central time)?    (b) Japan?    (c) Sweden (Europe)?

13. A plane takes 12 hours to fly from Adelaide to Cape Town, South Africa. If Shaunna leaves Adelaide at 10 am, what is the local time when she arrives in Cape Town?

14. Robert in Tasmania wants to call his brother living in Scotland, UK when the time there is 4:30 pm daylight-saving time. At what time should Robert make his call?

15. (a) What are the names of the time zones in America?
    (b) If it is 8 am in Miami, USA (Eastern time), what is the time in Seattle, USA (Pacific time)?

16. Australia, Canada and the USA are about the same distance from west to east, but Australia has only 3 time zones while Canada and the USA (not counting Alaska or Hawaii) have 5 and 4 time zones respectively. Why do you think? (Hint: Look at the countries on a world globe or map.)

17. Indira flew from New Delhi, India to Sydney, leaving at 1830 and arriving the next day at 1200 local time. How long did her plane trip take?

18. The Superbowl is broadcast live from New York, USA (Eastern time) at 6:30 pm Monday. At what time and day is it seen in:
    (a) Sydney?    (b) Berlin, Germany (Europe)?    (c) Dublin, Ireland?

19. At what time (and day if appropriate) should I make an international phone call from Sydney in order to ring:
    (a) Tonga at 7 pm?    (b) Lebanon at 4:30 pm?    (c) Sri Lanka at 5 pm?
    (d) Barbados at 3:30 pm?    (e) Kenya at 6:30 pm?    (f) Afghanistan at 10 pm?

20. Lim calls his friend in Moscow, Russia (west) from Hong Kong, China. It is 10:45 pm in Hong Kong and they talk for 20 minutes. What is the local time in Moscow at the end of the phone call?

21. A plane takes 3 hours to fly from Wellington, NZ to Sydney. If Paula leaves Wellington at 1620, what is the local time when she arrives in Sydney?

22. What is the last place on Earth to have its sunset every day?

23. Kameriah calls her cousin in Uruguay from Sydney. Both places are having daylight saving. If Kameriah calls at 11:30 am, what is the time in Uruguay?
24. A plane leaves Hawaii on Monday at 12 noon and takes 6 hours to fly west to Tokyo, Japan.  
(a) When the plane crosses the International Date Line, what day does it become?  
(b) What is the local time in Tokyo when the plane arrives?  

25. A plane leaves Sydney at 1 pm Thursday and flies 20 hours to get to Paris, France (Europe). At what time does the plane arrive in Paris if daylight saving is operating in France?  

26. Liz flew west from Buenos Aires, Argentina (GMT − 3) to Melbourne (GMT + 10). To her surprise, she discovered that when she arrived in Melbourne it was the same time, 7:30 pm, as when she left Buenos Aires.  
(a) How long did her plane journey take?  
(b) Was it still the same day? If not, what day was it?  

**Just for the record**  

**HISTORY OF DAYLIGHT SAVING**  
In 1907, British builder William Willett noticed that the extra hours of daylight in the morning during summer were being ‘wasted’ because people were still asleep at this time. He proposed a scheme called summer time or daylight saving in which the whole country would put its clocks 1 hour forward so that the population would wake up and work earlier and have more daylight hours in the afternoon for recreation.  
Daylight saving was first trialled in Britain and Australia during the First World War as a means of conserving energy. In Australia, it was tried again three times during the Second World War and then on a regular basis from 1971. It was formally adopted in NSW in 1976 after people voted in favour of it by a ratio of 13:6. However, people in Queensland, Northern Territory and Western Australia voted against it in their referenda.  
1. Research the daylight-saving periods of Europe, the USA and Tasmania.  
2. Visit one of the many Internet websites that describe and explain daylight saving.  
3. How does daylight saving reduce crime, pedestrian fatalities and energy costs?  
4. Daylight saving is less popular in country areas. Why do you think?  
5. Some countries have daylight saving in winter. Why do you think?  

**Investigation: Researching time zones**  

1. Why is GMT also known as Z time, Zulu time or Zebra time?  
2. Which country does not follow its standard time zone, preferring ‘sun time’ instead?  
3. How is time measured in Antarctica?  
4. What is the local time in Australia’s external territories, such as Norfolk Island, Cocos Island and Christmas Island (Indian Ocean)?  
5. What time zone appears on your e-mails? What do initials such as EDT and PST mean?  
6. Which country stretches across 11 time zones?  
7. Which country stretches across 4 time zones but only uses one: GMT + 8?
Group activity: Crossword of the Earth

Across
3. Another name for longitude line
7. Most countries here are GMT + 1 hour
8. 135°W is this type of line
9. Half of the world
11. Book of maps
13. Type of circle whose centre is also the centre of Earth
15. Type of mile used in navigation
16. Places _______ of Greenwich are ahead of GMT
17. South Australia uses Australian _______
   Standard Time
21. International Date Line (abbr.)
22. No. of minutes’ time difference per degree of longitude
24. Parallel rings around the Earth
26. D in IDL
27. No. of hours AEST is ahead of GMT
28. Fraction of a circle’s circumference
29. S in AEST

Down
1. Shape of the Earth
2. Nautical mile per hour
4. South Pole continent
5. This place is the ‘centre’ of time
6. I in IDL
7. South American country named after the equator
10. Another name for latitude line
12. Where Greenwich is
14. Turn clocks forward for ______ saving
18. Places along here are neither north nor south
19. 6400 km for Earth
20. No. of degrees of longitude for 1 hour’s time difference
23. Tuesday becomes Wednesday when travelling _______ over the IDL
25. Perth is in Australia’s western time
**Group modelling activity: Plan an overseas holiday**

Use an atlas or a world globe to plan a trip to visit up to five different places in the world. Design an itinerary (schedule) that lists the places you’ll be visiting. You will need to take into account:

- distances between places
- mode of transport and travelling speeds: by air, land or sea
- arrival and departure times
- international time zones
- climate/seasonal conditions (these also affect the popularity of destinations).

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**Study tips**

**Switch off the TV and the mobile phone**

It is very easy to achieve nothing in 3 hours of ‘study time’ if much of it is spent on cleaning your desk, chatting with friends on the phone or Internet, having excessive fridge and TV breaks, or playing games on the computer. If you are serious about studying, you need to program into your study routine some blocks of time when you cannot be interrupted by phone calls or friendly visits. This is especially important when you have a big task at hand, such as preparing for an exam or completing a major assignment. Establish an arrangement with your family so that they know not to disturb you during your study time.

Get rid of all distractions. Don’t study in front of the TV—time passes very quickly if you do. Either study or watch TV, but don’t do both. You can listen to music or have the radio on in your room as long as it doesn’t affect your concentration. And those fun things you want to do? Do them during a study break as a reward for completing a significant amount of work.
Chapter review

Geometry of the Earth

1. Latitude and longitude
2. Great circle distances
3. Nautical miles and knots
4. Longitude and time differences
5. International time zones

Topic summary

This short chapter, *Geometry of the Earth*, introduced entirely new concepts and skills related to the geography and measurement (land and time) of the Earth. As well as the mathematics, a considerable amount of theory is involved in this topic, so be sure that all knowledge, rules, terminology and worked examples are included in your summary. This topic can be divided into three neat sections: latitude and longitude, calculating distances and calculating times. Students often experience difficulty in calculating differences in latitude, longitude and time, but such confusion may stem from not learning the topic fully. Aim to achieve a strong and structured understanding of all areas.

Make a summary of this topic. Use the chapter outline above as a guide. An incomplete mind map has been started below. Use your own words, symbols, diagrams, boxes and highlighting. Make connections, look for general principles, and include personal observations and reminders. Use the questions in *Your say* below to think about your understanding of the topic. Gain a ‘whole picture’ view of the topic and identify any weak areas.

[Diagram with equations and conversion factors]

Arc length of a circle

\[ l = \frac{\theta}{360} \times 2\pi r \]

Nautical miles and knots

1 M = 1.852 km
1° = 60 M

Latitude and longitude

Great circle distances

\[ r = 6400 \text{ km} \]

Time zones

Local time
1 hour = 15°
4 min = 1°
Your say: Reflecting about the topic

- Have you satisfied the outcomes listed at the front of this chapter?
- What was the most important thing that you learned?
- How did you feel about the topic? Did you enjoy it?
- What was new?
- What are your weaknesses? What will you need to study more?
- How will you revise and summarise this topic?

Chapter assignment

1. What are the position coordinates of the points A, B, C and D on this diagram of the Earth?

2. The city of Albury has coordinates (36°S, 147°E).
   (a) Which coordinate refers to longitude?
   (b) How many degrees is Albury north of the South Pole?
   (c) Broome has coordinates (18°S, 122°E). What is the difference in longitude between Albury and Broome?
   (d) Hence calculate the local time in Broome (ignoring time zones) when it is 4:30 pm in Albury.

3. What can be found at the 180°W meridian of longitude?

4. Are these small circles or great circles?
   (a) the 128°E meridian       (b) the 45°N parallel       (c) the Equator

5. Calculate the difference in latitude between Carnarvon (25°S, 113°E) and Dubbo (32°S, 148°E) and state which city is further north.

6. Amsterdam, Netherlands is 15° north and 122° west of Seoul, South Korea (37°N, 127°E). What are the coordinates of Amsterdam?

7. The pendulum of a grandfather clock is 0.9 m long.
   Use the formula \( l = \frac{\theta}{360} \times 2\pi r \) to calculate the arc length swept by the ball of the pendulum if the central angle is 15°. Answer to the nearest centimetre.
8. (a) Use the arc length formula to calculate the great circle distance between Tokyo, Japan (35°N, 139°E) and Mt Isa (20°S, 139°E), to the nearest kilometre. (The radius of the Earth is 6400 km.)

(b) What is the time difference between Tokyo and Mt Isa?

9. Perth and Scone have the coordinates (32°S, 116°E) and (32°S, 151°E) respectively.

(a) Is the 32°S parallel of latitude a small or large circle?

(b) Calculate the distance between Perth and Scone along this circle if its radius is 5400 km. Answer to the nearest kilometre.

10. (a) What great circle runs through points S and T?

(b) Calculate the angular distance between S and T.

(c) Hence, calculate the shortest distance between S and T in nautical miles, given that 1° of latitude equals 60 nautical miles.

(d) Calculate the shortest distance between S and T to the nearest kilometre:

(i) using the arc length formula with \( r = 6400 \) km

(ii) by applying the conversion 1 M = 1.852 km to your answer in part (c)

(e) Which answer in part (d) is more accurate? Give a reason for your choice.

11. A cargo ship sails from Port Moresby, Papua New Guinea (9°S, 146°E) to Townsville (19°S, 146°E). Calculate:

(a) the length of the ship’s journey in nautical miles

(b) the speed of the ship in knots if this distance is covered in 18 3/4 hours

(c) the length of the ship’s journey in kilometres (1 M = 1.852 km)

(d) the speed of the ship in km/h (correct to 1 decimal place)

12. In Sydney, the Opening Ceremony of the 2000 Olympic Games began at 7 pm Friday and was televised live around the world.

(a) At what time was the ceremony seen in the following places if Sydney is usually 10 hours ahead of GMT but daylight saving applied during the Games?

(i) Chicago, USA (GMT − 6)

(ii) India (GMT + 5.5)

(iii) Greece (GMT + 2)

(b) Why do you think the opening ceremony of the Olympic Games in Sydney was held at night?

13. A plane flies from the Pacific island of Nauru (0°, 167°E) to Kampala, Uganda (0°, 32°E).

(a) Along what great circle is the plane flying, and in what direction?

(b) Calculate the distance between Nauru and Kampala in nautical miles.

(c) If the plane is flying at 600 knots, how long will it take to get to Kampala?

(d) Calculate the time difference between Nauru and Kampala (ignoring time zones).

(e) If the plane leaves at 7 pm Sunday, what will be the local time in Kampala when it arrives (ignoring time zones)?

14. A yacht sails 45 km at an average speed of 7 knots. Calculate how long this journey takes, in hours and minutes.
15. What is the time in Brisbane (AEST) when it is:
   (a) 4 pm in Perth?  (b) 6 am in Adelaide?  (c) 2:30 am in Hobart?

16. The time in Anchorage, Alaska (USA) is 9 hours behind GMT while the time in Lusaka, Zambia is 2 hours ahead of GMT.
   (a) When the time in Anchorage is 0800, what is the time in:
       (i) Lusaka?  (ii) London?
   (b) When the time in Lusaka is 1800, what is the time in:
       (i) Anchorage?  (ii) London?

17. The time in Baghdad, Iraq (33°N, 44°E) is 7 hours ahead of the time in the Falkland Islands (ignoring time zones).
   (a) What line of longitude runs through the Falkland Islands?
   (b) When it is 1540 Monday in the Falkland Islands, what is the time in Baghdad?
       Answer in 12-hour time.

18. A plane flies due south from Melbourne at an average speed of 459 knots for 4½ hours.
   (a) How far does it travel in nautical miles?
   (b) What is its current position if the coordinates of Melbourne are (37°S, 145°E)?
       Answer to the nearest degree.

19. (a) Calculate the difference in latitude between Naples, Italy (41°N, 14°E) and Bali, Indonesia (8°S, 115°E).
   (b) Which city is further west?
   (c) Calculate the time difference between the two cities (ignoring time zones).
   (d) What is the local time in Bali when it is 5:30 pm Thursday in Naples (ignoring time zones)?

20. Kerrie, living in Perth, wants to call her sister living in Los Angeles, USA when the time there is 12 noon Sunday. At what time should she call if Perth is GMT + 8 and Los Angeles is usually GMT − 8 but the USA is on daylight-savings time?

21. A plane leaves Darwin on Thursday at 6 pm and travels east for 8 hours to reach Samoa.
   (a) When the plane crosses the International Date Line, what day does it become?
   (b) If Darwin is GMT + 9.5 and Samoa is GMT − 11, what is the time in Samoa when the plane arrives there?