

CHAPTER 14 · GENERAL NAVIGATION

Convergency and Conversion Angle

Meridian convergence · Great circle tracks · D-I-I-D rule · Radio bearings · Conversion angle

IN THIS CHAPTER

- › Meridians and Convergency
- › GC Track and Convergency
- › Worked Examples 1–3
- › Radio Bearings
- › Practice Questions (10)
- › The Convergency Formula
- › The D-I-I-D Rule
- › Conversion Angle
- › Worked Examples 4–6

Meridians and Convergency

Meridians are great semi-circles that join the geographic North and South Poles. Because they all connect at the same two points, they cannot remain parallel to each other — they *must* converge at the poles. Understanding exactly *how much* they converge, and *at what rate*, is fundamental to great circle navigation.

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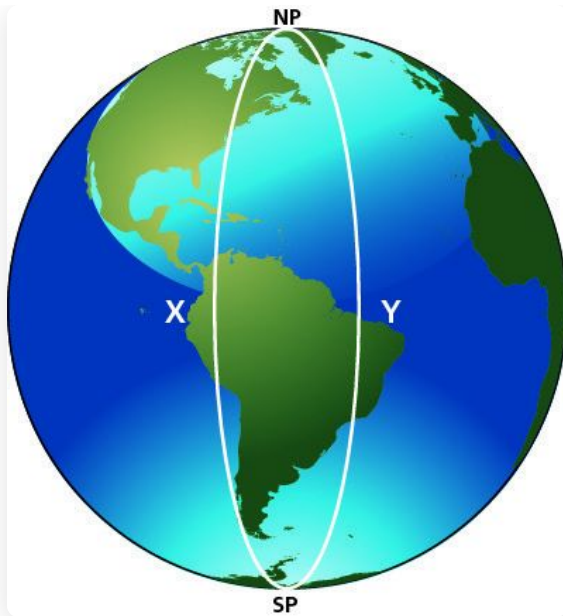


Figure 1 — Meridians diverge from the North Pole, are parallel at the Equator, then converge again toward the South Pole

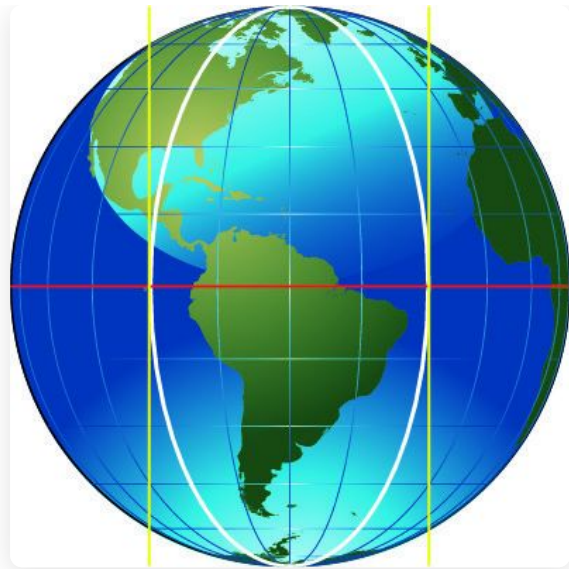


Figure 2 — At the Equator, any two meridians are exactly parallel to each other — convergence is zero

The Three Key Facts About Meridian Convergence

- **At the Equator:** any two meridians are exactly parallel. No matter how far apart they are in longitude, they never incline toward each other at the Equator. Convergence = 0° .
- **At either Pole:** meridians converge to a single point. The angle between two meridians at the Pole equals exactly their difference in longitude. If two meridians are 60° of longitude apart, they meet at the Pole at an angle of exactly 60° . Convergence = Change of Longitude.
- **At intermediate latitudes:** convergence is between 0° and the change of longitude — proportional to the sine of the latitude.

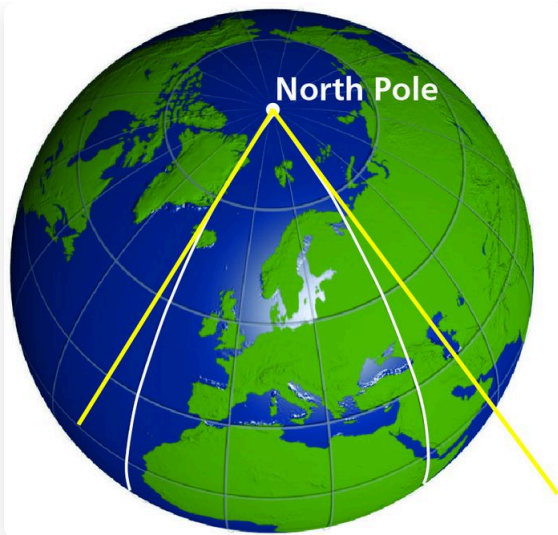


Figure 3 — At the Pole, the angle between two meridians equals exactly their change of longitude

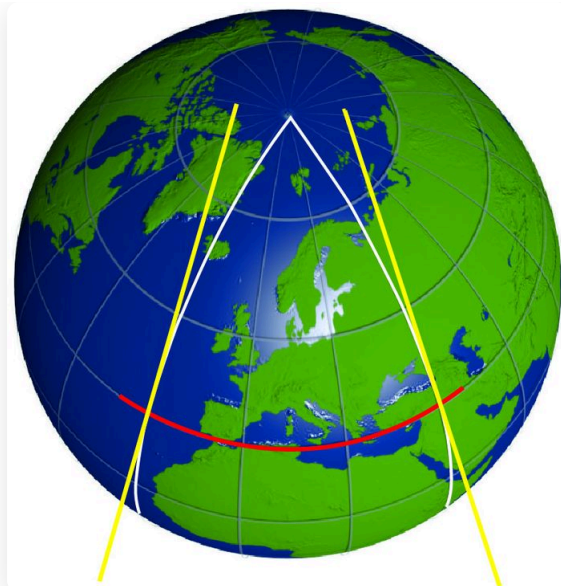


Figure 4 — At intermediate latitude, convergence is proportionally between 0° (Equator) and ch.long (Pole)

The Convergency Formula

From the observations above, convergence varies between zero (at the Equator) and the full change of longitude (at the Poles). The factor that controls this is the sine of the latitude. This leads directly to the formula:

$$\text{Convergency} = \text{Change of Longitude} \times \sin(\text{Latitude})$$

Where latitude is the common latitude of both meridians, or mean latitude when they differ

Why Sine of Latitude?

The sine function has exactly the right behaviour: $\sin(0^\circ) = 0$ at the Equator, and $\sin(90^\circ) = 1.0$ at the Poles. At 30°N , $\sin(30^\circ) = 0.5$, so convergency is exactly half the change of longitude. At 45°N , $\sin(45^\circ) = 0.707$, so convergency is about 70.7% of the change of longitude.

Latitude	$\sin(\text{lat})$	Effect on Convergency
0° (Equator)	0.000	No convergency
20°	0.342	34.2% of ch.long
30°	0.500	50% of ch.long
45°	0.707	70.7% of ch.long
60°	0.866	86.6% of ch.long
90° (Pole)	1.000	100% of ch.long

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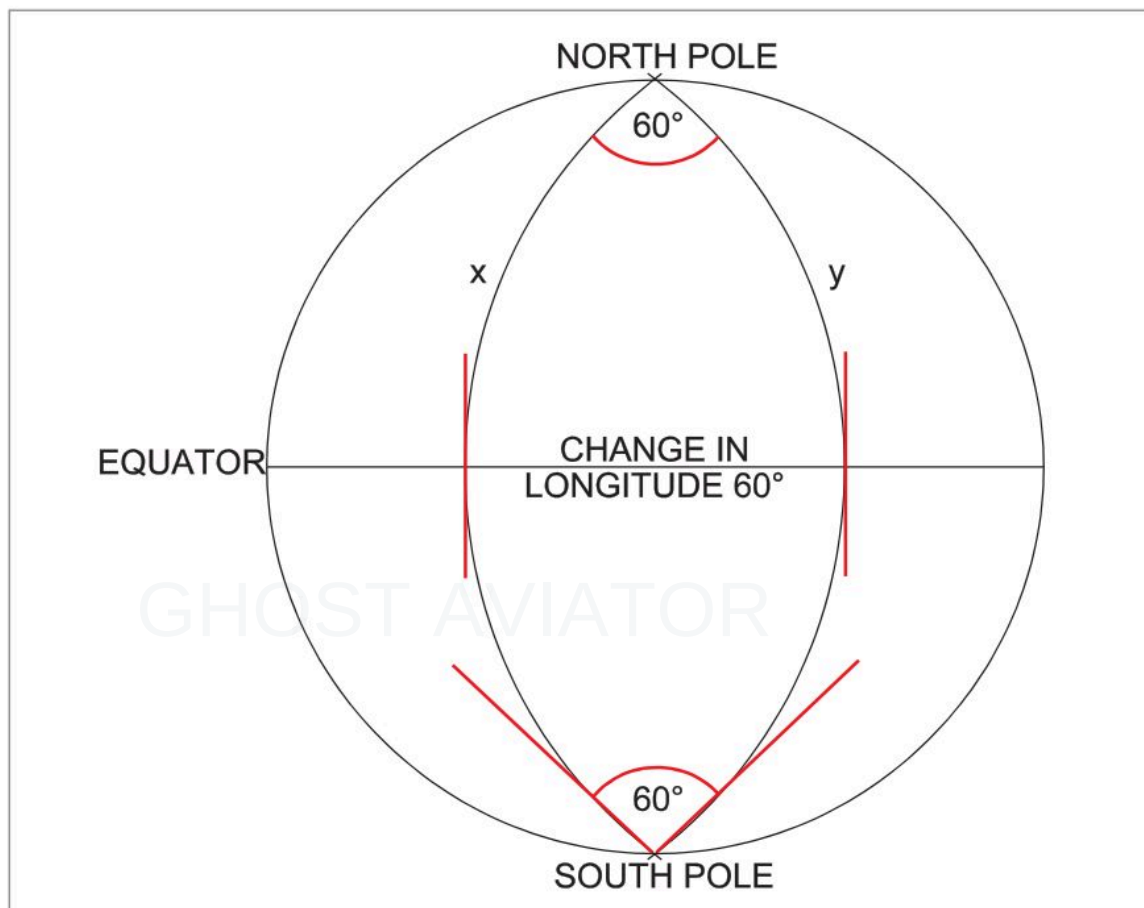


Figure 14.5 — Converging and diverging meridians

Figure 5 — Convergency shown as the angle of inclination between two meridians — with worked table showing values at Equator (0) and Pole (1.0)

The 30°N Worked Example

Consider two meridians 40° of longitude apart, at latitude 30°N:

CALCULATION

Convergency = Change of Longitude $\times$ sin(Latitude)

Convergency = $40^\circ \times \sin(30^\circ) = 40^\circ \times 0.5 = 20^\circ$

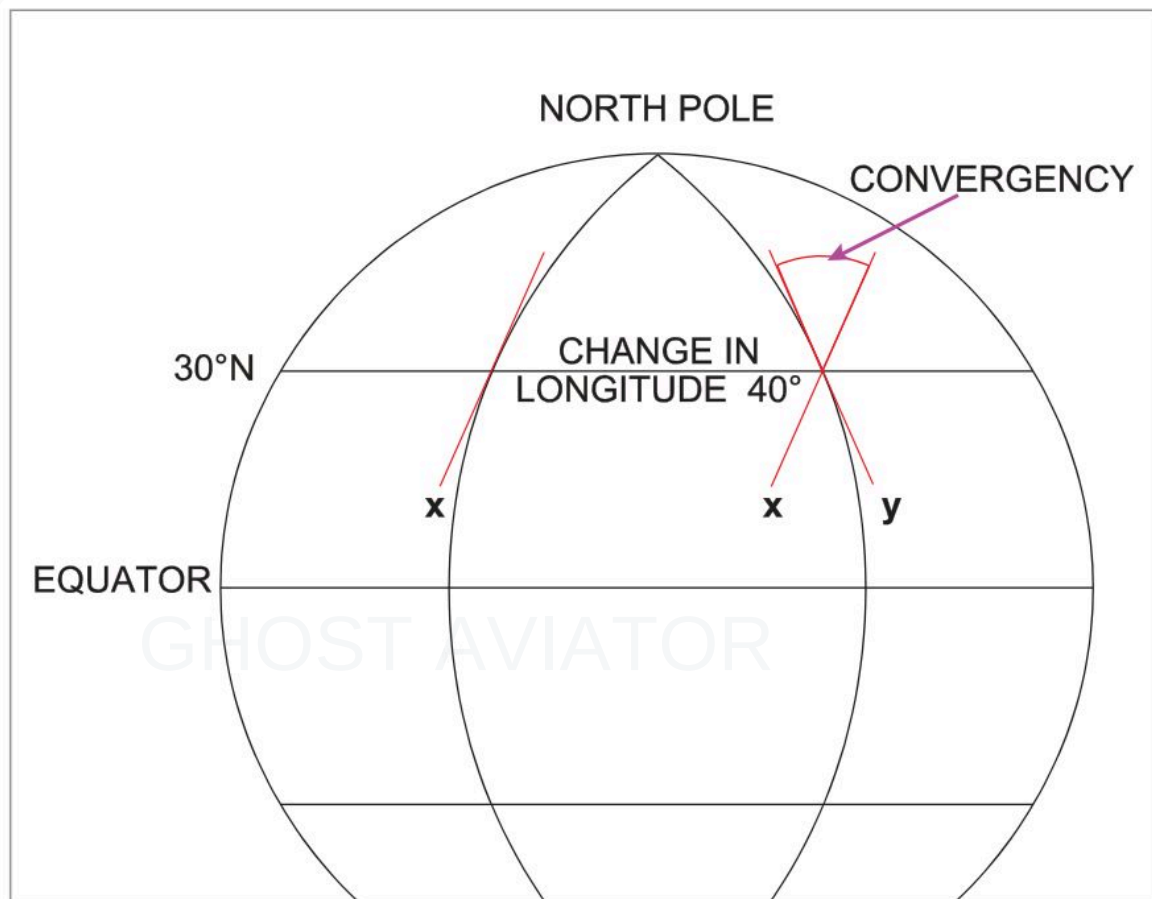


Figure 14.6 Convergence

Figure 6 — Tangents drawn to two meridians at 30°N — the angle between them is $20^\circ (= 40^\circ \times 0.5)$

When the Two Points are at Different Latitudes

In practice, most great circle routes go from one latitude to another — the two endpoints are not on the same parallel. In this case there is no single "latitude" to insert in the formula. The rigorous solution requires the *mean latitude* of the great circle route itself, which is closer to the nearer pole than the mid-latitude between the two endpoints.

However, the difference between sine of mid-latitude and sine of mean latitude is small unless the change of longitude is very large. For exam purposes and practical navigation, **mid-latitude** is used in the formula.

Great Circle Track and Convergence

At any point on the Earth, True North is defined by the direction of the local meridian. If you fly a great circle route, you will cross different meridians — and because those meridians are inclined to each other, your great circle track angle (measured from True North) will change continuously throughout the flight.

The amount by which a great circle track changes direction between two meridians is exactly equal to the convergence between those two meridians.

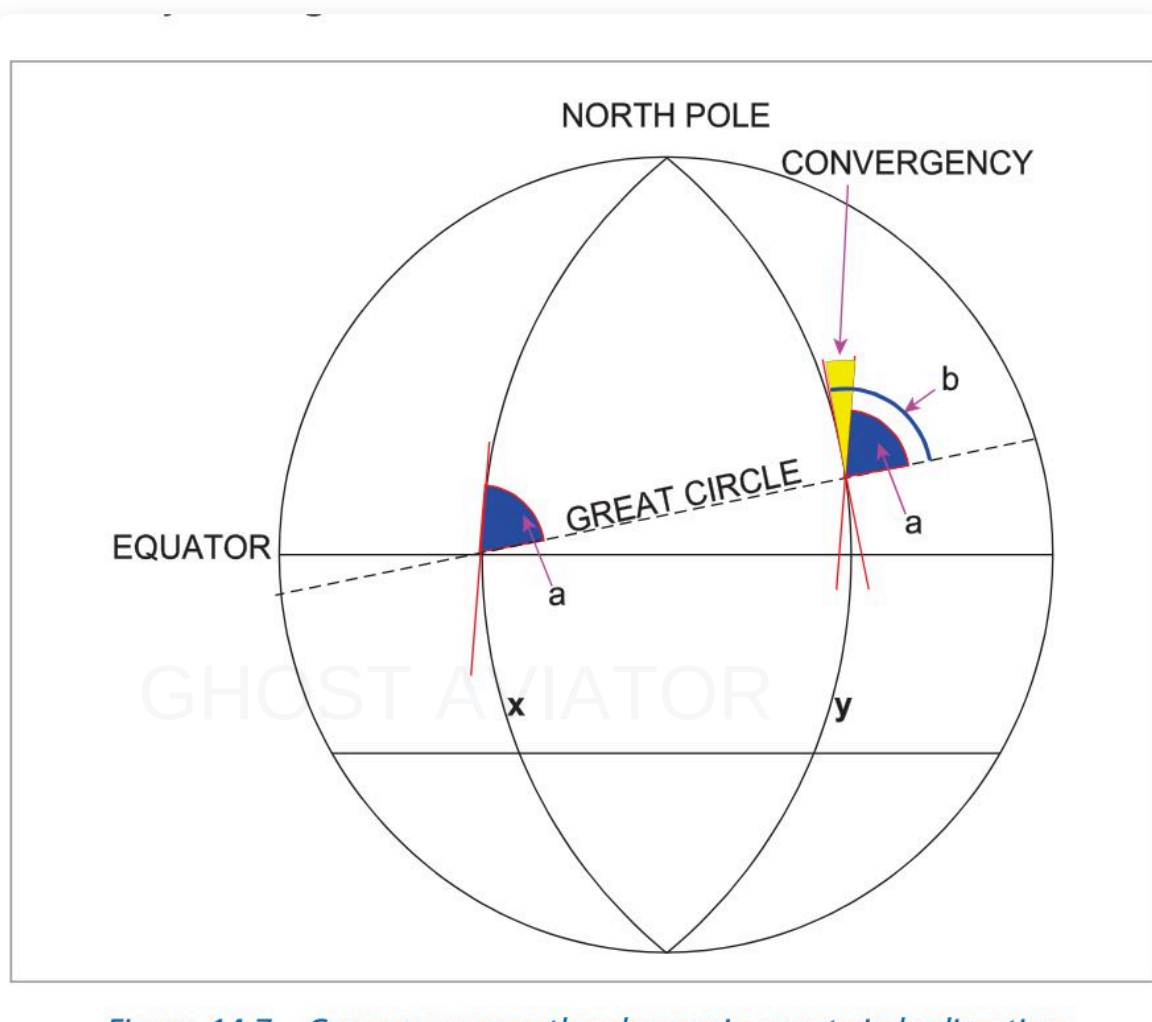


Figure 7 — A great circle cutting meridians X and Y — the angle 'a' at X and angle 'b' at Y differ by exactly the convergence between the meridians

Why a Rhumb Line Curves

A rhumb line (constant true track) appears as a straight line on a Mercator chart but as a curved line on a conformal conic chart. The reason is that to maintain a *constant* bearing from True North — and True North itself is rotating (because the meridians are converging) — the path must continuously curve. A rhumb line must compensate for meridian convergence in order to keep its track angle constant.

Conversely, a great circle — which is the shortest path between two points on the sphere — appears curved on a Mercator chart (curving toward the nearer pole) but as a straight line on a Lambert conformal chart (because the meridians themselves converge on that projection).

KEY RELATIONSHIP

The great circle track changes by the amount of convergency between its endpoints. If convergency = 8.5° , the GC track at arrival is 8.5° different from the GC track at departure — the D-I-I-D rule tells you in which direction.

The D-I-I-D Rule

When flying a great circle route, the track angle changes continuously. The D-I-I-D diagram tells you the direction of that change for any combination of hemisphere and direction of travel.

Northern Hemisphere	Southern Hemisphere
Going East ↑ Track INCREASES	Going East ↓ Track DECREASES

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Going **West**
↓ **Track DECREASES**

Going **West**
↑ **Track INCREASES**

The mnemonic **D-I-I-D** stands for the four cells read clockwise from top-left: *Decreases — Increases — Increases — Decreases* (starting with SH going West = Increases, going around). More usefully, remember the two rules for the Northern Hemisphere (where most of our traffic is):

NORTHERN HEMISPHERE SUMMARY

Going East → Track INCREASES (e.g. 060° becomes 068.5° at destination)

Going West → Track DECREASES (e.g. 313° becomes 305° at departure point)

How to Apply the Rule

Step 1: Calculate convergency ($\text{ch.long} \times \sin \text{mid-lat}$).

Step 2: Look up D-I-I-D for your hemisphere and primary direction of travel.

Step 3: Add or subtract convergency from the departure track to get the arrival track.

Step 4: Take the reciprocal of the arrival track to get the initial track from B to A.

Alternative: Parallel Construction Line

Draw the initial track from A. Parallel it across to B (draw a line at the same angle to the vertical). The convergency angle is then visible as the angle between this parallel line and the meridian at B. Add the two angles to get the track at B; take the reciprocal for the reverse direction. Both methods give the same answer.

Worked Examples 1–3

Worked Example 1 — Initial GC Track Between Two Points

Given: Initial GC track from A ($40^{\circ}00'N$ $002^{\circ}00'W$) to B ($50^{\circ}00'N$ $010^{\circ}00'E$) is $060^{\circ}(T)$. Find the initial GC track from B to A.

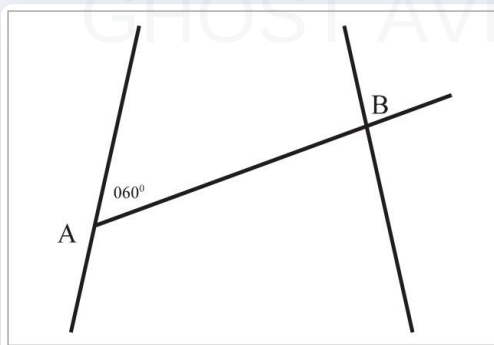


Figure 14.10 — Meridians converging northwards

Figure 8 — Diagram for Example 1 — A is on the left (W) meridian, B on the right (E) meridian; initial track 060° from A toward NE

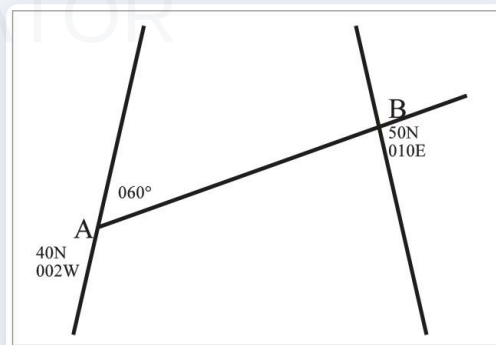


Figure 14.11 — Checking the diagram for sense

Figure 9 — Checking the diagram: B is north and east of A, confirmed by latitude/longitude comparison

Step 1 — Draw the diagram. In the Northern Hemisphere, meridians converge northward. The initial track is $060^{\circ}(T)$ — going NE. A is on the W meridian, B on the E meridian.

Step 2 — Check the diagram. B ($50^{\circ}N$, $010^{\circ}E$) should be north and east of A ($40^{\circ}N$, $002^{\circ}W$). ✓ North because $\text{lat } B > \text{lat } A$. ✓ East because $010^{\circ}E$ is east of $002^{\circ}W$.

Step 3 — Calculate convergency.

Change of longitude = $002^{\circ}W$ to $010^{\circ}E = 12^{\circ}$

Mid-latitude = $(40^\circ + 50^\circ) \div 2 = 45^\circ\text{N}$; $\sin 45^\circ = 0.7071$

Convergency = $12^\circ \times 0.7071 = 8.5^\circ$

Step 4 — Apply D-I-I-D. Northern Hemisphere, going East → track INCREASES. Track at A = 060° . Track at B (arrival) = $060^\circ + 8.5^\circ = 068.5^\circ$.

Step 5 — Reciprocal. Track from B to A = $068.5^\circ + 180^\circ = 248.5^\circ(\text{T})$

Answer: Initial GC track from B to A = $248.5^\circ(\text{T})$

Worked Example 2 — Finding an Unknown Longitude

Given: Initial GC track from C ($36^\circ 00'\text{N}$ $015^\circ 00'\text{E}$) to D ($42^\circ 00'\text{N}$) is $300^\circ(\text{T})$; final track at D is $295^\circ(\text{T})$. Find: (a) longitude of D; (b) GC track at 011°E .

Step 1 — Find convergency. Track changed from 300° to 295° = change of 5° . Going West in NH → track DECREASES ✓ ($300^\circ \rightarrow 295^\circ$).
Convergency = 5° .

Step 2 — Find change of longitude.

Mid-latitude = $(36^\circ + 42^\circ) \div 2 = 39^\circ\text{N}$; $\sin 39^\circ = 0.629$

Convergency = $\text{ch.long} \times \sin(39^\circ)$

$5^\circ = \text{ch.long} \times 0.629 \rightarrow \text{ch.long} = 5^\circ \div 0.629 = 8^\circ$

C is at 015°E and going west → D is at $015^\circ - 8^\circ = 007^\circ\text{E}$

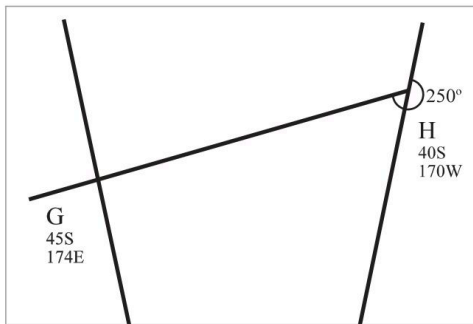


Figure 14.16 Meridians converging southwards

Figure 10 — Southern hemisphere meridians — meridians converge southward; for Q3 the setup reverses

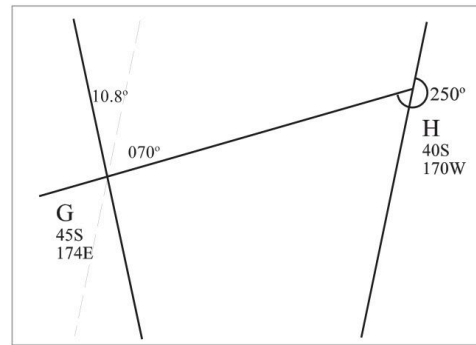


Figure 14.17 Drawing in a parallel

Figure 11 — Parallel construction: extend track from H, add convergency angle at G to find reciprocal

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Step 3 — Track at mid-longitude. Longitude 011°E is midway between 015°E and 007°E. Therefore the track is midway between 300° and 295° = **297.5°(T)**

Answers: (a) Longitude of D = 007°E · (b) Track at 011°E = 297.5°(T)

Worked Example 3 — Southern Hemisphere Route

Given: Initial GC track from H (40°00'S 170°00'W) to G (45°00'S 174°00'E) is 250°(T). Find initial GC track from G to H.

Step 1 — Draw the diagram. Southern Hemisphere → meridians converge southward. H is at 170°W, G is at 174°E. Crossing the anti-meridian (180°): change of longitude = (180° – 170°) + (180° – 174°) = 10° + 6° = **16°**

Step 2 — Calculate convergency.

Mid-latitude = (40° + 45°) ÷ 2 = 42.5°; sin 42.5° = 0.676

$$\text{Convergency} = 16^\circ \times 0.676 = \mathbf{10.8^\circ}$$

Step 3 — Apply D-I-I-D. Southern Hemisphere, going West → track INCREASES. Track at H (departure) = 250° . Track at G (arrival) = $250^\circ + 10.8^\circ = 260.8^\circ$.

Step 4 — Reciprocal. GC track from G to H = $260.8^\circ - 180^\circ = \mathbf{080.8^\circ(T)}$

Answer: Initial GC track from G to H = $080.8^\circ(T)$

Conversion Angle

Consider the situation in the diagram below. Two meridians are 40° of longitude apart. A rhumb line connects A ($30^\circ\text{N } 020^\circ\text{W}$) to B ($30^\circ\text{N } 020^\circ\text{E}$) along the parallel of latitude — this RL has a constant direction of $090^\circ(T)$ throughout.

A great circle connecting the same two points does NOT follow the parallel. Because the GC is the shortest path between the points on the sphere, it arcs toward the nearer pole (northward in the Northern Hemisphere for an easterly track). At A, the GC heads off on a direction *less* than $090^\circ(T)$ — it starts by heading slightly north of east. At B, it arrives on a direction *greater* than $090^\circ(T)$ — it arrives heading slightly south of east. At the mid-longitude (000°E/W), the GC direction = the RL direction = $090^\circ(T)$.

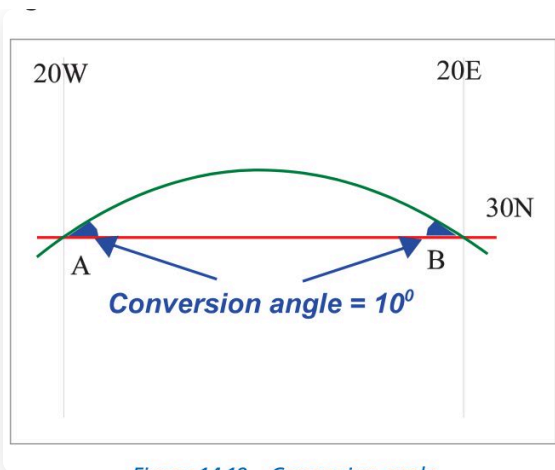


Figure 12 — Rhumb line (090° constant) vs great circle — RL shown as straight, GC bows toward the north pole between A and B

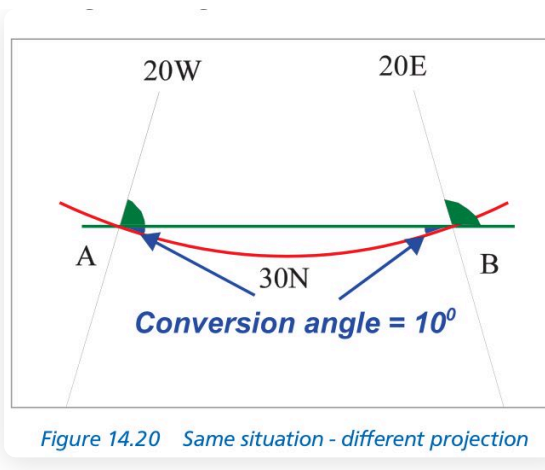


Figure 13 — Same geometry on a different projection — GC appears straight, RL curves; relative positions unchanged

Deriving Conversion Angle

In the example above:

- Convergency = $40^\circ \times \sin(30^\circ) = 40^\circ \times 0.5 = 20^\circ$
- The GC track changed 20° between A and B
- The RL track is 090° throughout and equals the GC at the midpoint
- So at A, GC = $090^\circ - 10^\circ = \mathbf{080^\circ(T)}$
- At B, GC = $090^\circ + 10^\circ = \mathbf{100^\circ(T)}$
- The difference between GC and RL at either endpoint = $\mathbf{10^\circ}$

This difference — between the great circle direction and the rhumb line direction at a given point — is called the **Conversion Angle (CA)**. In this case, $CA = 10^\circ$.

Notice that CA is exactly *half* the convergency. This is always the case (for routes between two points at the same latitude; it is also used as an approximation for routes at slightly different latitudes).

$$\text{Conversion Angle} = \frac{1}{2} \times \text{Convergency}$$

$$= \frac{1}{2} \times \text{Change of Longitude} \times \sin(\text{Mean Latitude})$$

Which Direction to Apply CA?

The GC always bows toward the nearer pole. Therefore:

- In the **Northern Hemisphere**, the GC arcs northward → at the departure point, GC is *more northerly* (smaller track number for E-bound; larger for W-bound) than the RL.
- In the **Southern Hemisphere**, the GC arcs southward → at the departure point, GC is *more southerly* than the RL.

Equivalently, at the departure point: **RL = GC ± CA**. Use the D-I-I-D/logical reasoning to determine the sign for your specific situation.

Radio Bearings and Conversion Angle

Radio waves travel along great circle paths over the surface of the Earth. When a VOR, NDB, or VDF station measures a bearing to or from an aircraft, that bearing is a **great circle direction**. For navigation plotting on a Mercator chart (where rhumb lines appear as straight lines), you must convert from great circle to rhumb line before plotting.

The Correction

Apply the Conversion Angle to the GC bearing to obtain the RL bearing:

FORMULA

$$\text{RL bearing} = \text{GC bearing} \pm \text{CA}$$

The sign depends on which hemisphere and which direction (D-I-I-D logic)

Important: Apply CA at the Measurement Point

This is a critical, frequently examined point. If the GC bearing is measured at the *aircraft*, apply CA at the aircraft's position. If measured at the *station*, apply CA at the station's position. The CA correction is position-specific.

VOR BEARINGS

A VOR radial is a bearing measured from the station (QDR). It is a great circle direction. To plot a VOR radial on a Mercator chart, apply CA to convert to RL before plotting. On a Lambert chart, the correction is very small and often ignored for routine navigation.

NDB/ADF BEARINGS

An NDB bearing is measured at the aircraft. The ADF needle points along a great circle to the beacon. Apply CA at the aircraft's position to convert to a RL for Mercator plotting.

Practical Example

If the GC track from A to B is $100^{\circ}(\text{T})$ and $\text{CA} = 4^{\circ}$, the RL track at A is found by: GC is 100° , which is slightly south of east in the NH. The RL (which is more 'direct', less curved) will be slightly closer to $090^{\circ} \rightarrow \text{RL} = 100^{\circ} - 4^{\circ} = \mathbf{096^{\circ}(\text{T})}$... but check the exact geometry for your specific question (see Worked Example 6 below).

Worked Examples 4–6

Worked Example 4 — Convergency, RL Track, and GC from K to J

Given: J ($58^{\circ}12'N$ $004^{\circ}00'W$) and K ($58^{\circ}12'N$ $006^{\circ}00'E$). Both at same latitude.

(a) Convergency:

Ch.long = $004^{\circ}W$ to $006^{\circ}E = 10^{\circ}$; Latitude = $58^{\circ}12'N$; $\sin 58.2^{\circ} = 0.851$
Convergency = $10^{\circ} \times 0.851 = 8.5^{\circ}$

(b) RL track from J to K:

Both points are at the same latitude ($58^{\circ}12'N$). The RL connecting two points on the same parallel of latitude is the parallel itself — a constant direction of **$090^{\circ}(T)$** (due East).

(c) Initial GC track from K to J:

Going West in NH $\rightarrow$ track DECREASES going west. The RL midpoint track = 090° .

GC at K (going west) = RL at midpoint – CA = $090^{\circ} - 4.25^{\circ} = 085.75^{\circ}...$
but we want from K to J (opposite direction). RL from K to J = $270^{\circ}(T)$.

GC at K going west = $270^{\circ} + CA = 274.25^{\circ}$

Or equivalently: reciprocal of GC from J to K at K = $(090^{\circ} - 4.25^{\circ} = 085.75^{\circ})$ reversed $\rightarrow$ reciprocal = 265.75° ? Let us use the formula directly:

Initial GC from K to J = $270^{\circ} + CA = 270^{\circ} + 4.25^{\circ} = \mathbf{274.25^{\circ}(T)}$ (GC bows northward, so at K going west it starts more northerly than 270° $\rightarrow$ larger number)

Answers: (a) 8.5° · (b) $090^{\circ}(T)$ · (c) $274.25^{\circ}(T)$

Worked Example 5 — INS Waypoint Changeover

Given: WP1 (53°N 030°W) → WP2 (53°N 020°W) → WP3 (53°N 010°W). An FMS/INS steers GC legs. What is the track change on passing WP2?

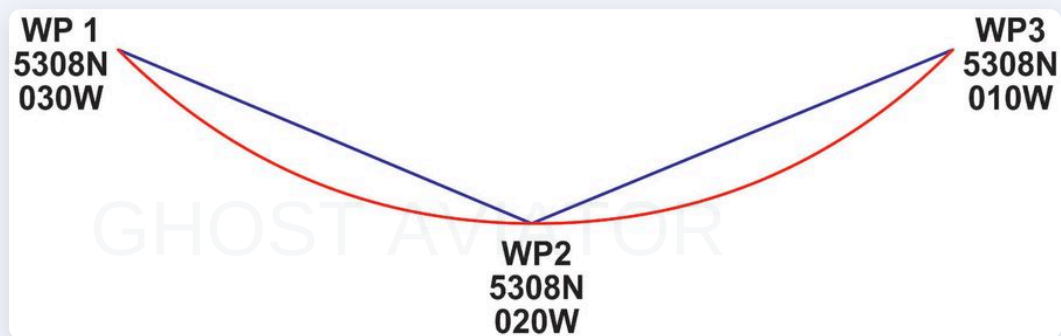


Figure 14 — INS waypoint changeover — WP1 to WP3 shows two consecutive GC legs at 53°N; a left turn occurs at WP2

Step 1 — RL track all the way. All three WPs are on 53°N. RL track = 090°(T) throughout.

Step 2 — GC legs. Each leg has ch.long = 10°, mean lat = 53°N, $\sin 53^\circ = 0.799$.

CA per leg = $\frac{1}{2} \times 10^\circ \times 0.799 = 4.0^\circ$

GC leg 1 (WP1→WP2): departs WP1 on 086°, arrives WP2 on 094°

GC leg 2 (WP2→WP3): departs WP2 on 086°, arrives WP3 on 094°

Step 3 — Track change at WP2. Approaching WP2 on 094°(T); at changeover, FMS reverts to 086°(T) for the new leg → change = $094^\circ - 086^\circ = 8^\circ$ decrease. This is a *left turn* at the waypoint. Answer: **8° decrease (d)**

Answer: (d) — an 8° decrease of track angle on passing WP2

Worked Example 6 — GC to RL Conversion at a Point

Given: A (55°N 000°E/W), B (54°N 010°E). Initial GC track from A to B is 100°(T). Find the RL track at A.

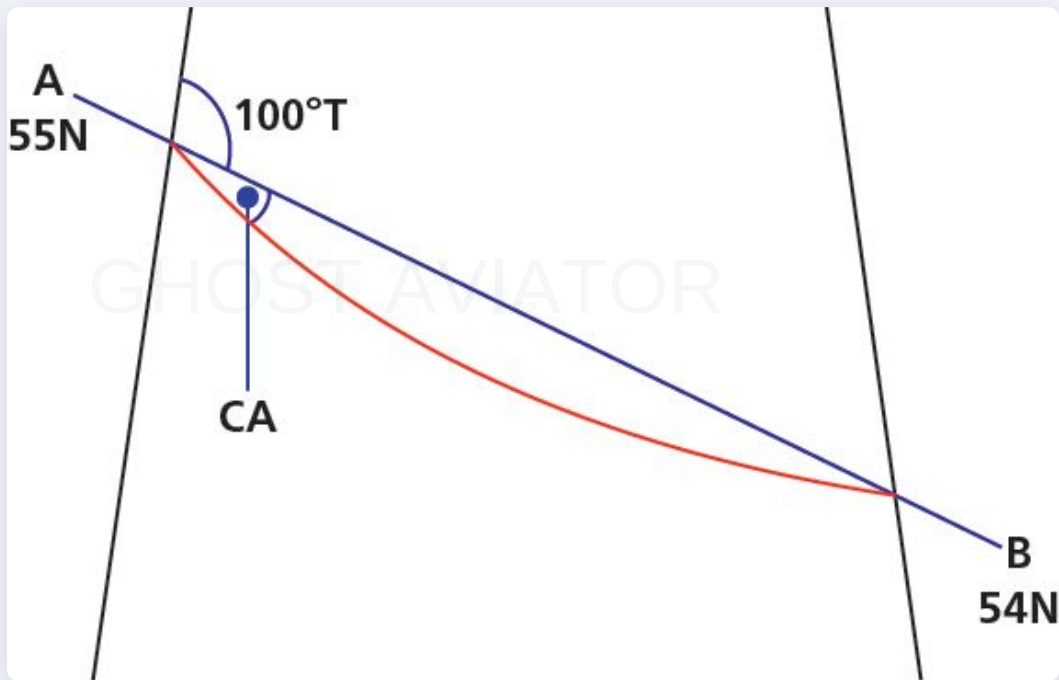


Figure 15 — Diagram for Example 6 — GC track 100°(T) at A; applying CA gives RL track 104°(T)

Step 1 — Calculate CA.

Ch.long = 10°; Mean latitude = $(55^\circ + 54^\circ) \div 2 = 54.5^\circ\text{N}$; $\sin 54.5^\circ = 0.814$

$$CA = \frac{1}{2} \times 10^\circ \times 0.814 = 4.07^\circ \approx 4^\circ$$

Step 2 — Direction of correction. We're going SE (100°T) in the NH. The GC is MORE northerly than the RL (GC bows toward N pole). At A, GC < RL. Therefore RL = GC + CA = 100° + 4° = **104°(T)**

⚠ CRITICAL POINT — APPLY CA AT THE MEASUREMENT POSITION

The answer is $104^{\circ}(T)$ because the GC bearing is measured AT A and we apply CA at A. If the GC bearing were given at B, we would apply CA at B's position instead. **Never apply CA at the wrong endpoint.**

Answer: (c) RL track at A = $104^{\circ}(T)$

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Practice Questions

The following 10 questions are taken from the chapter. These are calculation-based questions — draw a diagram for each before calculating. Tap to reveal each answer.

Q1 The convergency of the meridians through M and N (Southern hemisphere) is 12° . If the rhumb line track from M to N is $249^{\circ}(T)$, what is the GC track: (a) from M to N? (b) from N to M?

ANSWER: (A) $243^{\circ}(T)$ • (B) $075^{\circ}(T)$

RL = $249^{\circ}(T) \rightarrow$ SW direction in SH going west. CA = $12^{\circ}/2 = 6^{\circ}$.

SH going West $\rightarrow$ track INCREASES going west. GC is more southerly than RL at departure (bows toward S pole).

(a) GC from M $\rightarrow$ N at M: RL 249° is SW. GC more southerly = larger number.
GC at M = $249^{\circ} - 6^{\circ} = 243^{\circ}(T)$.

(b) GC at N (arrival from M) = $249^{\circ} + 6^{\circ} = 255^{\circ}$. Reciprocal = $255^{\circ} - 180^{\circ} = 075^{\circ}(T)$.

Q2 The GC bearing of position B (in latitude $30^{\circ}00'S$) from position A ($30^{\circ}00'S$, $165^{\circ}00'E$) is $100^{\circ}(T)$. What is (a) the GC track from B to A? (b)

the longitude of B?

ANSWER: (A) 260°(T) • (B) 155°W

Both at 30°S — same latitude. RL track = 090°(T) (due east).

GC bearing from A to B = 100°(T). $CA = GC - RL = 100^\circ - 90^\circ = 10^\circ$.

$CA = \frac{1}{2} \times \text{ch.long} \times \sin(30^\circ) \rightarrow 10^\circ = \frac{1}{2} \times \text{ch.long} \times 0.5 \rightarrow \text{ch.long} = 40^\circ$.

B is east of A at 165°E $\rightarrow$ longitude of B = $165^\circ + 40^\circ = 205^\circ\text{E} = 155^\circ\text{W}$.

(a) GC at B going from B to A: arrive on 100° – reciprocal $\rightarrow$ GC from B = $(100^\circ + 40^\circ = 140^\circ)$... Actually: GC at arrival at B = $100^\circ - CA + CA = 80^\circ$ (T)

RL side; use track method: departure 100°, SH going east DECREASES $\rightarrow$ arrival = $100^\circ - 20^\circ$ (convergency) = 80° ; reciprocal = 260°(T).

Q3 The RL from D (30°00'N 179°00'W) to C is 090°(T). Initial GC from C to D is 287°(T). What is (a) the GC from D to C? (b) the approximate latitude and longitude of C?

ANSWER: (A) 073°(T) • (B) 30°N 111°W

Both at 30°N (same RL direction 090° means same latitude). RL = 090°, so C is east of D.

GC from C to D = 287°(T). $CA = |287^\circ - 270^\circ| = 17^\circ$. (RL from C to D = 270°; GC from C to D = 287°; difference = $17^\circ = CA$).

(a) GC from D to C at D: going east in NH $\rightarrow$ track increases. GC at D = $090^\circ - CA = 073^\circ$ (T) (more northerly than RL).

(b) $CA = \frac{1}{2} \times \text{ch.long} \times \sin(30^\circ) \rightarrow 17^\circ = \frac{1}{2} \times \text{ch.long} \times 0.5 \rightarrow \text{ch.long} = 68^\circ$.

C is east of D: $179^\circ\text{W} + 68^\circ\text{E} = \text{longitude } 179^\circ - 68^\circ = 111^\circ\text{W}$. Position C = 30°N 111°W.

Q4 The GC track from A to B measures 227°(T) at A and 225°(T) at B. What is the convergency and in which hemisphere?

ANSWER: 2° CONVERGENCY — NORTHERN HEMISPHERE

Track changed from 227° to 225° — a decrease of 2° . Going SW (225° -ish direction).

Decrease going SW = going west component in NH (track decreases going W in NH) ✓

Convergency = $|227^\circ - 225^\circ| = 2^\circ$. **Northern Hemisphere.**

Q5 (a) At what latitude is the convergency between two meridians equal to twice their convergency at 20°N ? (b) Is there a latitude where convergency = three times the value at 20°N ?

ANSWER: (A) 43°N APPROX · (B) NO

Convergency at $20^\circ\text{N} = \text{ch.long} \times \sin(20^\circ) = \text{ch.long} \times 0.342$.

Twice that = $\text{ch.long} \times 0.684$. Need $\sin(\text{lat}) = 0.684 \rightarrow \text{lat} = \arcsin(0.684) \approx 43^\circ\text{N}$.

Three times = $\text{ch.long} \times 1.026 \rightarrow \sin(\text{lat}) = 1.026$ — impossible because sine cannot exceed 1.000. No such latitude exists.

Q6 (a) A and B: GC from B to A = $268^\circ(\text{T})$, GC from A to B = $092^\circ(\text{T})$. i) Which hemisphere? ii) RL track from A to B? (b) C and D: GC from C to D = $063^\circ(\text{T})$, RL from D to C = $240^\circ(\text{T})$. i) Which hemisphere? ii) Initial GC from D to C?

ANSWER: (A)I SH · (A)II $090^\circ(\text{T})$ · (B)I SH · (B)II $237^\circ(\text{T})$

(a): GC $A \rightarrow B = 092^\circ$, GC $B \rightarrow A = 268^\circ$. If NH and going east, track increases.

Reciprocal of $268^\circ = 088^\circ \neq 092^\circ$. Difference = $4^\circ = 2 \times \text{CA}$. Going east: $088^\circ \rightarrow 092^\circ$ is an increase of 4° — but GC increases going EAST in NH. ✓ for NH?

Actually: arrival track at B = 092° ; reciprocal of arrival = 092°

$+180^\circ = 272^\circ \neq 268^\circ$. Convergency = $|268^\circ - (180^\circ + 092^\circ)| = |268^\circ - 272^\circ| = 4^\circ$.

Going east in which hemisphere gives DECREASE? SH. So **Southern Hemisphere.**

Both A and B must share same latitude for RL = 090° (the difference between GC and RL is symmetrical). RL $A \rightarrow B = 090^\circ(\text{T})$.

(b): GC $C \rightarrow D = 063^\circ(T)$ (NE direction). RL $D \rightarrow C = 240^\circ(T) \rightarrow$ RL $C \rightarrow D = 060^\circ(T)$. $CA = |063^\circ - 060^\circ| = 3^\circ$. GC is more northerly ($063^\circ > 060^\circ$ in NE quadrant means less northerly actually... 063° vs 060° : 063° is MORE EASTERLY/LESS NORTHERLY. In SH, GC bows southward, so $GC > RL$ for NE track. Confirms SH.

GC from D to C: RL = 240° . $CA = 3^\circ$. In SH going SW (west component), track INCREASES. GC at D = $RL + CA = 240^\circ - 3^\circ = 237^\circ(T)$. (GC is more southerly = further from north = larger number for SW direction).

Answer: (b)i **Southern Hemisphere**; (b)ii GC $D \rightarrow C = 237^\circ(T)$

Q7 Position X: $64^\circ 00'S$ $011^\circ 50'W$. Position Y: $64^\circ 00'S$ $005^\circ 10'W$. Give: (a) convergency between meridians of X and Y; (b) initial GC from Y to X; (c) RL track from X to Y.

ANSWER: (A) 6° · (B) $267^\circ(T)$ · (C) $090^\circ(T)$

Both at $64^\circ S \rightarrow$ same latitude. RL from X to Y = $090^\circ(T)$ (Y is east of X: $005^\circ 10'W$ is east of $011^\circ 50'W$).

Ch.long = $011^\circ 50' - 005^\circ 10' = 6^\circ 40' = 6.67^\circ$. $\sin(64^\circ) = 0.899$.

(a) Convergency = $6.67^\circ \times 0.899 = 6.0^\circ$ (rounded).

(b) RL from Y to X = $270^\circ(T)$. $CA = 3^\circ$. SH going west $\rightarrow$ track INCREASES. GC at Y = $270^\circ - 3^\circ = 267^\circ(T)$.

(c) RL from X to Y = **$090^\circ(T)$** .

Q8 Position A: $55^\circ 30'N$ $004^\circ 35'W$. Position B: $64^\circ 00'N$ $022^\circ 37'W$. (a) Calculate convergency. (b) If RL track from A to B is $313^\circ(T)$, what is the approximate initial GC track from B to A?

ANSWER: (A) $15.5^\circ (\approx 16^\circ)$ · (B) $125^\circ(T)$

(a) Ch.long = $022^\circ 37' - 004^\circ 35' = 018^\circ 02' \approx 18.03^\circ$. Mid-lat = $(55.5^\circ + 64.0^\circ)/2 = 59.75^\circ N$; $\sin 59.75^\circ \approx 0.864$.

Convergency = $18.03^\circ \times 0.864 = 15.58^\circ \approx 15.5^\circ$ (call it 16°)

(b) RL track $A \rightarrow B = 313^\circ(T)$ (NW direction, going west in NH).

$$CA = 15.5/2 \approx 7.75^\circ \approx 8^\circ.$$

Going W in NH $\rightarrow$ track DECREASES. At A (departure): GC is more northerly than RL.

For NW track: 'more northerly' = closer to $360^\circ/0^\circ$ = larger track number (e.g. 320° is more northerly than 313°).

$$GC \text{ initial at A} = RL + CA = 313^\circ + 8^\circ = 321^\circ(T).$$

$$GC \text{ final at B (arrival)} = 313^\circ - 8^\circ = 305^\circ(T) \text{ [track decreased going west } \checkmark].$$

$$GC \text{ from B to A} = \text{reciprocal of arrival track at B} = 305^\circ - 180^\circ = \mathbf{125^\circ(T)}$$

■ **Instructor's Note** — The derivation above uses: 'more northerly for NW track = larger number' because in the NW quadrant (270° – 360°), numbers closer to 360° are more northerly (e.g. 320° is more northerly than 310°). This is the source of confusion noted in the teaching notes. The published answer of $125^\circ(T)$ is correct and is reproduced verbatim. If your diagram gives a different derivation, verify your hemisphere assumption and check whether you are applying D-I-I-D at the departure or arrival point.

Q9 The initial GC track from B to A is $245^\circ(T)$ and the RL track from A to B is $060^\circ(T)$. If mean latitude = $53^\circ N$ and longitude of B = $002^\circ 15' E$, what is the longitude of A?

ANSWER: $010^\circ 15' W$

RL $A \rightarrow B = 060^\circ(T)$; RL $B \rightarrow A = 240^\circ(T)$. GC $B \rightarrow A = 245^\circ(T)$. Going SW in NH $\rightarrow$ track DECREASES going west. But $B \rightarrow A = 245^\circ$ vs RL $B \rightarrow A = 240^\circ$. Difference = $5^\circ = CA$. (For SW track, the GC at B going toward A is more southerly than RL $\rightarrow$ larger number $\checkmark$ for SH? But we're at $53^\circ N$. Let us check: GC $B \rightarrow A = 245^\circ >$ RL $B \rightarrow A = 240^\circ$. NH going SW $\rightarrow$ track decreases going west, so GC at departure B should be LESS than RL? $245^\circ > 240^\circ$ contradicts this... Unless going SW we consider the eastern component: going eastward is the $A \rightarrow B$ direction. $A \rightarrow B$: RL = 060° , GC at A = $060^\circ - CA$. GC at B (arrival from A) = $060^\circ + CA$. GC from B = reciprocal of arrival = $(060^\circ + CA) + 180^\circ$. But GC $B \rightarrow A = 245^\circ$. So $240^\circ + CA = 245^\circ \rightarrow CA = 5^\circ$.
 $CA = \frac{1}{2} \times \text{ch.long} \times \sin(53^\circ) \rightarrow 5^\circ = \frac{1}{2} \times \text{ch.long} \times 0.799 \rightarrow \text{ch.long} = 12.5^\circ$.
B at $002^\circ 15' E$, A is west of B (track $A \rightarrow B$ is $060^\circ = NE$, so B is NE of A,

meaning A is SW of B, i.e. west). Longitude of A = $002^{\circ}15'E + 12.5^{\circ}$ west = $002^{\circ}15' + 12^{\circ}30' = 014^{\circ}45'$? Hmm — published answer is $010^{\circ}15'W$. ch.long = $002^{\circ}15'E$ to $010^{\circ}15'W = 012^{\circ}30'$. $CA = \frac{1}{2} \times 12.5^{\circ} \times 0.799 = 4.99^{\circ} \approx 5^{\circ}$. ✓ Longitude of A = **$010^{\circ}15'W$** .

Q10 A and B are both in the Southern hemisphere and the convergency of their meridians is 8° . The initial GC track from A to B is $094^{\circ}(T)$. B is at $23^{\circ}00'S$ $020^{\circ}00'W$. What is position A?

ANSWER: $23^{\circ}00'S$ $040^{\circ}30'W$

GC A→B = $094^{\circ}(T)$. SH going east → track DECREASES. $CA = 8^{\circ}/2 = 4^{\circ}$. At A: GC = 094° , RL = GC + CA (for SH eastbound, GC is more southerly than RL, so GC > RL → $094^{\circ} > RL$ → RL = $090^{\circ}(T)$).

RL = 090° means A and B are on the same latitude: $23^{\circ}00'S$.

Convergency = ch.long $\times \sin(23^{\circ})$ = ch.long $\times 0.391 = 8^{\circ}$ → ch.long = $20.46^{\circ} \approx 20^{\circ}30'$.

B is at $020^{\circ}W$. GC from A→B is 094° (easterly), so B is east of A. Longitude of A = $020^{\circ}W + 20^{\circ}30'$ west = **$040^{\circ}30'W$** .

Position A = **$23^{\circ}00'S$ $040^{\circ}30'W$** . (RL track A→B = $090^{\circ}(T)$) ✓

Quick Answer Key

Q1 $243^{\circ} / 075^{\circ}$	Q2 $260^{\circ} / 155^{\circ}W$	Q3 $073^{\circ} / 30^{\circ}N 111^{\circ}W$	Q4 $2^{\circ} NH$	Q5 $43^{\circ}N / No$
Q6 $SH / 090^{\circ} /$	Q7 $6^{\circ} / 267^{\circ} / 090^{\circ}$	Q8 $16^{\circ} / 125^{\circ}$ 🚩	Q9 $010^{\circ}15'W$	Q10 $23^{\circ}S 040^{\circ}30'W$

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