The Geometry of "toward Mecca"

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Issue 3
September 18, 2025

INTRODUCTION

Muslims worldwide are exhorted, with regard to their obligatory daily formal prayers, to face in the direction of The Kaaba, a stone structure located within the Sacred Mosque in the city of Mecca (Makkah), Saudi Arabia. It is considered the holiest place in Islam. The concept is often described in the popular press as praying "toward Mecca", thus the title of this article.

While that mandate seems simple on the surface, when we consider that the Earth is not flat, we immediately run into the matter of how should "in the direction of The Kaaba" be interpreted if one is at any significant distance from The Kaaba. Countless works have been written by Islamic scholars over the years on this matter. Two pragmatic interpretations as a basis for making the determination (giving quite different results) have been "taught" by different Islamic advisors. One survives today as seemingly the "most widely accepted".

In this article I examine these two interpretations from a standpoint of the geometric premises they seem to imply. No attempt is made to judge which is the "most appropriate".

Background is given in geometric and cartographic matters of importance to the story.

1 CAVEAT

I am not a Muslim by faith nor an Islamic scholar or "expert". My perspective on this matter is from a strictly secular technical basis, predicated on widely-presented descriptions of the two interpretations said to have been recommended. I make no attempt to suggest which interpretation is "the most proper".

In the background material that follows, the various Islamic concepts and their descriptions in Arabic terms are not intended to be definitive nor claimed to be accurate. Rather, they are presented according to my best understanding, solely to allow me to provide a concise context for the secular technical discussion which is the aim of this article.

2 BACKGROUND

2.1 Arabic words

Many of the items mentioned here are by tradition (or prescription). formally described by words of the Arabic language. I will not ordinarily present these in Arabic (for one thing, I have no skill in that language, editorial or otherwise), nor in the formal ALA-LC[1] transliteration using an augmented Roman alphabet. Rather, I will generally use one of the "popular" Romanizations.

Often, more than one such is in common use throughout the entire contemporary scope of journalism, reference books, and such. I will in each case choose one and use it consistently. I do not mean by so doing to suggest that this is the "most appropriate" Romanization (although in each case I believe I have justification for considering it "valid").

However, in many cases I will give in a footnote the Arabic word itself, the ALA-LC transliteration (in italics), and other commonly-seen Romanizations or transcriptions.

In the case of a city of particular interest (in the past, and to a great extent still today, known as "Mecca"), my understanding is that the preferred Romanization of the short form of its actual name (in Arabic) is now "Makkah" [2].

But in keeping with what many American readers may be familiar with[3] I will use here the form "Mecca". I will not here join in the argument as to whether or not the use of "Mecca" is erroneous or disrespectful.

I will similarly use the form "Kaaba" (out of several widely used Romanizations) for the holy structure that figures prominently in this matter. And I will use "Quran"[4] here for the Muslim religious text.

Finally, although the Quranic exhortation is, to paraphrase, to "face in the direction of the Sacred Mosque", I will here generally speak of "facing Mecca" or the direction "toward Mecca" for the issue of interest, as again I suspect this is the phraseology most familiar to the reader.

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[1] American Library Association/Library of Congress

[2] مكة, *Makkah* (based on its short Arabic name), Mecca

[3] And as per the policy of the US Board on Geographic Names and as prescribed in the AP Style Guide.

[4] القــرآن, *al-qur'ān*, Qur'an, Koran

2.2 The Kaaba

The Kaaba[5] is a rectangular stone structure located in the Sacred Mosque[6] in Mecca, Saudi Arabia (also often called the Grand Mosque). It is considered to be the most holy place in Islam.

2.3 The exhortation to "face The Sacred Mosque"

The exhortation to "face the Sacred Mosque" (during formal prayer) appears many places in the Holy Quran. One citation often given is this:

> "Turn then Thy face in the direction of the Sacred Mosque" [Quran, Surah 2: Verse 144 (in part); I quote from the Yusuf Ali translation.]

This exhortation is today generally interpreted to mean specifically in the direction of The Kaaba.[7]

2.4 Qibla

The direction "of the Holy Mosque" is widely referred to as the *Qibla*[8], an Arabic word roughly meaning, literally, "direction".

3 THE REAL ANSWER

Of course, there is a technically-indisputable answer to the question "what is the direction toward Mecca" and that is along a (straight) line connecting the location of interest with Mecca. This of course always will pass through the Earth itself.

But that answer is not "usable" in the actual situation, which (without this being said) visualizes a direction to "face" during prayer that nominally lies in a horizontal plane.

4 GEODESY AND SPHERICAL GEOMETRY

4.1 The dilemma

The "instruction" to "face Mecca" seems at first simple. If we are at a certain location, not too far from The Kaaba, and have a map of the region, it would seem that we could just draw a line on the map from our location to Mecca and, with reference to a compass rose or such

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[5] الكعبـــة, *al-Ka'bah,* Ka'ba, Ka'bah, Kabah

[6] الحـرام المســجد, *Al-Masjid al-Ḥarām*

[7] Until, 624 CE it was interpreted as meaning to face the Temple Mount in Jerusalem.

[8] قبلـــة, Qiblah, Kiblah, Kibla

on the map, determine its compass direction–the direction "toward Mecca".

But there is a complication. The surface of the Earth is not flat, but rather is (approximately) a sphere. Thus things we do on a flat map do not precisely follow the corresponding reality on the Earth's surface. This comes to the fore in such matters as precise land surveying, even when relatively small distances are involved.

The precise result of our line-drawing exercise depends on the "projection" used for that map (a matter that I will discuss in detail shortly). And the person making this determination probably has no idea what that is, and the map he has might not even follow one of the recognized projections, or any one consistently across the map.

The "uncertainty", when we consider a point not too far from Mecca, is quite small. And of course extreme precision is not needed or useful in the matter of the direction of prayer. A Muslim, praying, is not expected to "face Mecca" (whatever that means, geometrically and anatomically) with a precision of one degree, or to any precision that is, so far as I know, prescribed.

However, if we now consider prayer at a point at a substantial distance from Mecca, this problem becomes much more consequential. If we draw a straight line on some map we have from say, Chicago to Mecca, the compass direction of the "track" that line represents, as it leaves our location, depends on the "projection" of the map we use.

Islamic scholars early realized the issue, and for many years there have emerged innumerable learned writings on how to deal with it.

5 RECOMMENDED PRACTICE

Many instructions to Muslims as to how to reckon the Qibla for their prayer location involve interpretations of the exhortation that imply one or the other of two basic geodesic premises, which we can describe thus:

a. The "rhumb line" premise: the direction toward Mecca from any place on the Earth is considered to be the compass direction of a track from that place to Mecca that navigators call a "rhumb line".

b. The "great circle" premise: the direction toward Mecca from any place on the Earth is considered to be the initial compass direction of the shorter arc of the *great circle* of the Earth passing through that location and Mecca.

These two premises will be described in detail shortly.

These two premises are wholly incompatible. At most locations they produce substantially different directions as "toward Mecca".

6 THE RHUMB LINE INTERPRETATION

6.1 The term

In the field of navigation, a rhumb line[9] (pronounced "rum") is a track on the Earth's surface that has a constant compass direction along its entire length.

6.2 Utility in sailing

It is convenient for a ship, sailing between two points, to follow the rhumb line between those points, as to do so the ship can be steered to maintain a constant compass heading.

6.3 A straight line?

From the definition of a rhumb line, we are tempted to say, "Oh, that is just a straight line". But no track on the surface of the earth (which approximates a sphere) is a "straight line" (which is at the root of the dilemma discussed here).

6.4 On a Mercator projection map

However, on a certain kind of map, called a "Mercator projection[10] map" ("Mercator map, for short), any rhumb line appears as a straight line. And the angle of that line (perhaps measured from the direction that indicates north) is in fact that constant compass direction of the rhumb line itself.

Thus we can see that such a map is useful to marine navigators. The rhumb line track between any two points can be constructed on the flat paper map merely by drawing a straight line, using a straightedge, between those two points. Its angle can then be measured with protractor, giving the constant compass heading to which the ship should be steered.

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[9] Its name in formal geometry is *loxodrome*.

[10] The term "projection" alludes to the fact that for many map types, the transform from the spherical surface of the Earth to the flat map is based on the metaphorical "projection" of the markings on a transparent "world globe" onto a surface that is either flat or which can be "flattened" without any stretching, which becomes the flat map. But the term is used for all map transforms, whether or not derived from such a projection" metaphor. The "Mercator projection" map transform is not derived from any such "projection" metaphor.

6.5 Another property of the Mercator map

Another property of the Mercator map is that the shape of any small region on the map is the same as it is on the surface of the Earth (to the extent that such is really meaningful).[11]

6.6 Wide usage

At one time the "maps of the world", or maps of some large region, in books and such, were almost always of the Mercator type.

6.7 As to "toward Mecca"

As the issue arose of determining the direction "toward Mecca" at some remote point, it was not an all unexpected that this would be visualized as being determined on a map that embraced that point and Mecca.

Perhaps one should draw a (straight) line from that point to Mecca on the map, ascertain the compass direction of that line as it departed the point of interest, and consider that direction as being the direction "toward Mecca".

Given that the Mercator map was almost universally used at the time for maps covering a substantial region, we could imagine this process as most likely being done on such a map. And it might have been comforting to the workers in this field that the compass direction of that drawn line (to Mecca) was in fact constant throughout its length. That line on the map represented a *rhumb line* on the surface of the earth.

Thus we can imagine the emergence of what I call the "rhumb line" interpretation of the exhortation to "face toward Mecca" during prayer.

7 THE GREAT CIRCLE INTERPRETATION

7.1 Great circles of a sphere

Geometers define a great circle of a sphere as a circle on the surface of a sphere whose center is at the center of the sphere. A great circle

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[11] However, the "scale" varies greatly with latitude. One manifestation of this is that a Mercator map shows the area of Alaska and Australia as about the same, whereas the actual area of Australia is about 4.5 times that of Alaska.

has the largest diameter possible for a circle lying in the surface of a sphere.[12]

To help visualize this on the Earth (treating it as if it were a sphere, as we do in this matter) note that the equator is a great circle of the Earth, and any meridian of longitude is a great circle of the Earth. There are an infinity of great circles beyond those special cases.

Parallels of latitude (except for the Equator) are not great circles of the sphere. (They have lesser diameters than the Equator.)

7.2 The shortest distance

An important finding by early geometers was that the shortest "track" along the earth's surface from one point to another is the shorter arc of the great circle passing though those points (I will spare the reader the proof of this).

A consequence is that a mariner planning a leg of a journey from point "A" to point "B" would have to sail the shortest distance if he followed a a route along the great circle passing though those two points.

Of course to do this precisely, the ship would have to be steered on a compass heading that continually changed during the trip. Pragmatically, that heading might be calculated for numerous short segments of the trip, but the calculation in any case was laborious. And executing this required accurate knowledge of the location of the ship at any time (none of that being required for "rhumb line sailing").

These maneuvers were so tedious that "great circle sailing" was probably not widely adopted until relatively-modern times.

7.3 As to "toward Mecca"

Over time, Islamic scholars seemingly became in intrigued by the significance of great circles of the Earth. Seemingly, a new interpretation of "toward Mecca" came into play. I will paraphrase it as:

> The direction toward Mecca at a certain location is the direction of, as it leaves that location, the shorter arc of the great circle of the Earth that passes through that location and Mecca.

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[12] It is sometimes said that the length of that curve is the "circumference" of the sphere. That is a bit of a stretch of the term "circumference", which rigorously applies only to plane figures, but it is useful in discussions of the Earth.

8 THE DIFFERENCE

I note that at a location such as Chicago, the great circle interpretation leads to a "direction toward Mecca" that is substantially different than would be determined under the rhumb line interpretation of the exhortation, well outside the degree of uncertainty that would seem reasonably to apply to this matter.

Using the "standard" coordinates for Chicago and for the Kaaba, we get, for the "direction toward Mecca" (to the nearest tenth of a degree):

- For the "rhumb line" interpretation: 100.8°
- For the "great circle" interpretation: 48.6°

That is a substantial difference—over 1/8 of a circle in angle.

9 SOME INTERESTING FACTS

- At any location on Earth whose latitude is anything north of 21.4° S (the "opposite" of the latitude of Mecca) the direction toward Mecca as reckoned under the *great circle* premise will be more to the north than that reckoned under the *rhumb line* premise. (We earlier saw an example of this for a Chicago location.)

- If we consider a location (likely aboard ship) whose longitude is 140.2° W (the "opposite" of the longitude of Mecca), and whose latitude is anything north of 21.4° S (the "opposite" of the latitude of Mecca), then the direction toward Mecca as reckoned under the *great circle* premise will be 0° (due north). That great circle in fact passes the North Pole on its way to Mecca.

  Of course, that result will seem counterintuitive to some.

- If we consider a location (likely aboard ship) whose longitude is 140.2° W and whose latitude is 21.4° S (that is, it is "exactly opposite" in its location to Mecca), then the direction toward Mecca as reckoned under the *great circle* premise is undefined. That is, **any** great circle through that point (regardless of its orientation) will also pass through Mecca. There is no direction that is uniquely "toward Mecca".

  Of course, that result will be confounding to some.

10 ANOTHER APPROACH

One might suggest that the "logical" conceptual way to determine the direction "toward Mecca" as a direction in the horizontal plane is this:

First, we (somehow) look along a line actually leading to Mecca in the 3-dimensional context. This would be a direction downward from the horizontal, maybe by quite a bit. Our line of gaze unavoidably passes through the Earth.

Then, without any rotation, we elevate our gaze (much as we might move a surveyor’s transit in the elevation direction only) until it was horizontal. It would seem reasonable to consider the compass direction of our gaze then as the direction “toward Mecca”.

But that compass direction is identical to the one obtained under the “great circle” premise. (The proof is in Appendix A.)

11 OTHER METAPHORS

11.1 A vertical beam of light

This metaphor is sometimes advanced in favor of the “great circle” interpretation for the Qibla.

Suppose we are at a point sufficiently far from Mecca that it is well below the horizon (the distance being enough that the effect of the curvature of the earth would have to enter into usable calculations).

Imagine now that we have a powerful beam of light directed directly upward from The Kaaba, and we can see that (owing to scattering in the atmosphere) from our point of observation. We observe the compass direction toward the beam of light at the horizon. Some suggest that this is clearly the direction “toward Mecca”.

That direction is precisely the one that would result under the great circle premise I described earlier. (The proof is in Appendix A.)

11.2 A different vertical beam of light

Some might suggest that a better metaphor would have the beam of light arising from The Kaaba site not be vertical but rather be parallel to a vertical line at the point of observation.

We then again observe the compass direction toward this beam of light at the horizon.

That direction is also precisely the one that would result under the great circle premise I described earlier. (The proof is in Appendix A.)

12 THE DISTANCE TO MECCA

One is at first tempted to say that the distance from the remote point to Mecca, as would be along the two “tracks” implied by the two interpretations, is of no consequence toward the fulfillment of the Quranic exhortation or how we choose to interpret it, geometrically.

That notwithstanding, some Islamic scholars have advanced the notion a person is best thought of as “facing Mecca” if the direction he faces is considered to be the direction, leaving his location, of the shortest path to Mecca.

Thus, the “great circle” interpretation would be superior in that it implies a track “to Mecca” that is shorter than for the “rhumb line” interpretation.

13 CURRENT LEANING

From current writings, it seems as if the “great circle” interpretation of “toward Mecca” is the one to which the greatest attention is paid at this writing (2025). I have not confirmed this with any Islamic authorities or experts.

14 QIBLA CALCULATORS

There are available many tools to assist the practicing Muslim (perhaps while “on the road”) to determine the Qibla for his location, so he might observe it in connection with his obligatory prayers.

Some are self-contained instruments that include a magnetic compass to allow the result to be easily utilized (there typically not being a compass rose in the typical motel room or private residence), and their workings contain provisions for taking magnetic deviation into effect (since the basic “calculations” return a result in terms of true, not magnetic, compass direction). These tools often include a “directory” of their input parameters in terms of the name of the city.

Today, there are available many Qibla calculators as software for use with a computer or “smartphone” (online or via a downloadable application).

Some (few) of these calculators offer the user a choice between the “great circle” and “rhumb line” premises for the calculation. Their instructions do nor ordinarily include any commentary as to where and when each premise might properly be chosen. Often the “great circle” premise is the default.

Those that do not offer a choice seem to almost all follow the “great circle” premise (although that is almost never mentioned).

15 GREATER ACCURACY

The classical calculation of the Qibla at some location is based on approximating the Earth’s surface as a sphere. But the Earth’s surface is not a sphere. And, in the field of geodesy, when highly accurate results are desired, a “closer” approximation of the shape of the earth, but still a mathematically-tidy one, is as an *ellipsoid*. Several

“standard” ellipsoidal models, each defined by certain values of the defining parameters, are in use for various scientific purposes.

Such a solid figure does not have a “great circle”, which is defined only for a sphere. But there is an analogous concept, the curve on the surface of the ellipsoid that represents the shortest travel from one point to another, called a “geodesic”. (In fact, a great circle on a sphere is a special case of a geodesic.)

If it is felt that the property of the great circle that ultimately qualifies it to be used to determine the Qibla is that it is the shortest path to Mecca, it then follows that to be wholly precise in the face of the “ellipsoidal” approximation of the Earth’s surface we should determine the “departing” compass direction of the shorter arc of the geodesic through the location and Mecca.

Calculation of various matters for an ellipsoidal model, done on a rigorous analytical basis. is very arduous. But various workers have devised easier-to-use algorithms, often treating such things as geodesics as if they were polygons (with very many sides). Fairly recently (2013), Charles F F Karney published a set of algorithms that are considered very useful in this regard.

In any case, it turns out that for most points of practical interest, the precise calculation based on the ellipsoidal model of the Earth (however it is done) differs only trivially from that based on the spherical model.

For example, Wikipedia reports that for a location in San Francisco, for calculations based on a certain ellipsoidal model (the “GRS 80” model), the Qibla is calculated as 18.888°, while calculations based on the usual spherical model of the Earth’s surface give the Qibla as 18.933°, a difference of about 1/20 of a degree.

The tiny difference between the “ellipsoid-based” and the “sphere-based” result seems to me to be hardly of any import to the Muslim finding himself in Chicago and wanting to know how to face Mecca for his daily prayers.

Nonetheless, the publishers of some Qibla calculators brag about what is apparently their making the calculations using an ellipsoidal model of the surface of the Earth, often specifically pointing out that “the method of Karney” is used.

16 IN CLOSING

We sometimes hear that we should not attempt to understand or evaluate various premises for reckoning the Qibla using logic, geometry, trigonometry, or other mathematical tools. This is, “they”

say, because the Qibla is a matter of religious doctrine, which transcends such secular conceits.

Fair enough. As Hamlet says[13], “There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy.”

My work here, though, merely seeks to understand the technical implications of two (distinct) interpretations, described here in “secular” terms, apparently at times recommended by two camps of Islamic “experts”. I could hardly suggest that one or the other is “more appropriate”—that it is the best fulfillment of the exhortation in the Holy Quran to “face the Sacred Mosque”.

In any case, as I understand it, the ultimate Islamic doctrine on this matter is that each Muslim should determine the Qibla for his use as he is best able to do so.

17 ACKNOWLEDGEMENTS

Thanks to my wife Carla for her insightful copy editing and proofreading of this manuscript.

Thanks to my good friend and colleague (you know who you are) for the helpful comments on the presentation here.

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[13] Shakespeare, W, “Hamlet”, Act 1, scene 5

APPENDIX A

Proofs pertaining to the great circle premise

The surveyor's transit metaphor

[As described, in more human terms, in Section 10.]

Here we demonstrate that the azimuth indication of a surveyor's transit (here a metaphor for a human observer) aimed directly at The Kaaba is in fact the departure azimuth of the shorter portion of a great circle of the Earth through the point of observation and the location of the Kaaba.

We level the transit and orient the azimuth circle such that with the telescope pointed due north the azimuth circle reads 0°.

We then (somehow) point the telescope directly at The Kaaba (along a line that in essentially every case will pass through the Earth).

Now, with the azimuth axis of the transit locked, we "plunge" the telescope until it points straight down ("to the nadir"). It now points to the center of the Earth, and the elevation circle reads –90.0°. (Note that with the instrument leveled, its optical axis is horizontal; that is, it is tangent to the surface of the Earth.)

Consider now a plane defined by three points: the point of observation, The Kaaba, and the center of the Earth. Because the telescope, with its azimuth axis locked, located at one of those points (the point of observation), can be swung on its elevation axis to point to the other two of those points, its pointing direction always lies in that plane (the elevation axis is perpendicular to that plane).

Consider now a circle on the surface of the Earth that lies in that plane. Since that plane passes through the center of the Earth, this circle must be a great circle of the Earth.

We now elevate the transit telescope to the horizontal. Its aiming axis intersects the great circle[14]; it lies in the plane of that circle; and it is perpendicular to the radius of the circle at the point of intersection (the line from the center of the earth to the transit). Thus the telescope axis is now tangent to this great circle.

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[14] It actually misses by its height above the earth, a tiny discrepancy in the scale involved here.

A line tangent to a circle at a point is indistinguishable from an infinitesimal segment of the circle at that point. Thus the direction of the tangent is the direction of that infinitesimal segment of the circle. We can think the direction of that segment of the circle to be the “departure azimuth” of the circle—the direction in which we would initially move to travel along the circle.

Thus the azimuth of the line that is actually directly to the Kaaba is the departure azimuth of the shorter arc of a great circle of the Earth through both the current location and the location of The Kaaba.

Quod erat demonstrandum.

The “vertical beacon” metaphor

[As described in Section 11.1.]

I mention a metaphor involving a hypothetical “beacon” of light emitted vertically upward from The Kaaba, which can be seen by a person at a point a fair distance from The Kaaba. I asserted that, looking in a horizontal direction toward that “beacon”, the azimuth is again the departure azimuth of the shorter arc of the great circle of the Earth passing through the point of observation and The Kaaba.

The line of that beacon passes through the center of the Earth. Since it also passes through The Kaaba (its point of origin), it thus lies in the same plane mentioned in the earlier proof. Thus, the telescope would “aim at it” at any elevation (since all aiming lines of the telescope would lie in that plane). Thus the azimuth reading of the telescope would be the same as before, which we earlier demonstrated was consistent with the departure azimuth of the great circle of the Earth passing through the point of observation and The Kaaba.

Quod erat demonstrandum.

The “parallel beacon” metaphor

[As described in Section 11.2.]

I mention another metaphor involving a hypothetical “beacon” of light emitted upward from the Kaaba, parallel to the local vertical at the point of observation (potentially some substantial distance from The Kaaba), which can be seen by a person at that point. I assert that, looking in a horizontal direction toward that “beacon”, the azimuth is again the departure azimuth of the shorter arc of the great circle of the Earth passing through the point of observation and The Kaaba.

Now, the line of the beacon does not pass through the center of the Earth. But since it is parallel to the local vertical at the point of observation, both those lines lie in the same plane. Since a line in the

plane (the local vertical at the point of observation) passes through the center of the Earth, the plane of course passes through the center of the Earth

Since that plane includes the point of observation, the center of the Earth, and the location of the Kaaba, it is the same plane referred to in the two discussions just above.

With the aiming axis of the telescope pointed at the “beacon”, which lies in the plane, the azimuth of the telescope is that previously discussed.

Thus the azimuth of the telescope observing this beacon will be the same as the azimuth of departure. This metaphor is then consistent with the implications of the two previous cases.

Quod erat demonstrandum.

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