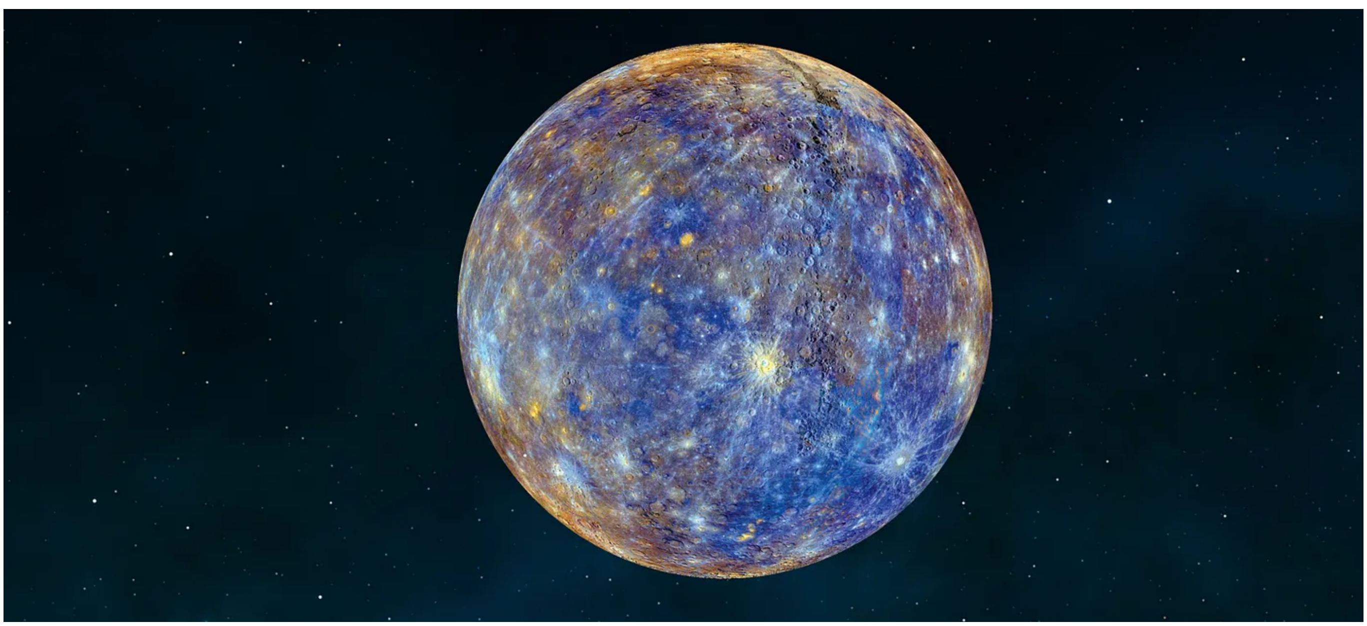
Mercury Retrograde Explained With Orbital Mechanics

Let's see exactly why Mercury appears to be in retrograde motion

Zack Fizell · Following

6 min read · Jan 25, 2022



I'm sure at some point in your life, you've heard someone talk about their lives falling apart during Mercury retrograde. What exactly is Mercury retrograde? Is it a real thing? Let's find out. (If you don't care about the technical aspect, scroll to the end of the article for the answer) the majority of bodies in a solar system. For our solar system, all of the planets orbit counterclockwise around the Sun. There are a few comets that move in a retrograde motion, Halley's Comet is one of those, meaning it orbits in a clockwise direction around the Sun. Retrograde motion can also be applied to rotation about an axis, but that doesn't pertain to Mercury retrograde.

If you look at that last paragraph again, you probably noticed that I said all of the planets orbit counterclockwise. So what about Mercury retrograde? Does it not actually exist? To us, as we observe Mercury from Earth, there are periods of time in which Mercury's motion across our night sky appears to reverse (depicted below). While we may observe it that way, Mercury's orbit does not, in fact, reverse. If that happened, our horoscopes wouldn't be the only thing we need to worry about. Since we orbit the Sun at a different velocity than Mercury, there are periods of time in which Mercury is "lapping" us, giving it the appearance of reversing direction.

Mercury Retrograde Time-lapse [credit to original photographer]

I can tell you all of this in words, but maybe it still doesn't make sense, so let's introduce some astrodynamics.

. . .

Astrodynamics problems wouldn't exist without gravity, so let's start with the basics: Newton's law of universal gravitation. The below equation applies for a system of two masses. In the equation, we have *G*, the universal gravity constant, *m*, the masses of our bodies, *r*, the position vector going from mass 2 to 1, and *F*, the gravity force on mass 1 induced by mass 2.

$$\vec{F}_{12} = -G\frac{m_1 m_2}{r_{21}^3}\ \vec{r}_{21}$$

This equation will be our starting point. To explain Mercury's retrograde motion, we need to obtain Mercury and Earth's orbits about the Sun. Since we do not need to be as accurate as possible, we can make a couple assumptions that will make the math simpler. We will assume that the mass of the planets are negligible compared to the Sun and that the Sun's gravitational force is the only force acting on our planets. These are not a terrible assumptions, but they are assumptions nonetheless.

Now, if we apply those assumption and Newton's law of universal gravitation to a two-mass system of the Sun and our planet of interest (Mercury and Earth will be assessed separately), we arrive at the following:

$$\ddot{\vec{r}}_{planet} = -G\frac{m_{sun}}{r^3_{planet}}\ \vec{r}_{planet} = -\frac{\mu_{sun}}{r^3_{planet}}\ \vec{r}_{planet}$$

Note that μ is called the standard gravitational parameter. It is the product of the universal gravitational constant and a body's mass. The above equation describes the motion of a planet orbiting the Sun (valid only for our assumptions). We can break the position vector into its Cartesian components (*x, y,* and *z* shown below). When we do that, we get the equations of motion for the planet of interest. Make note that the "planet" subscript was dropped on our Cartesian coordinates.

$$\ddot{x} = -\frac{\mu_{sun}}{(x^2+y^2+z^2)^{3/2}}\ x$$
$$\ddot{y} = -\frac{\mu_{sun}}{(x^2+y^2+z^2)^{3/2}}\ y$$
$$\ddot{z} = -\frac{\mu_{sun}}{(x^2+y^2+z^2)^{3/2}}\ z$$

The next step is solving the equations of motion numerically for both Mercury and Earth. I have outlined how to solve equations of motion using Python in article listed below, so I'll skip that process here.

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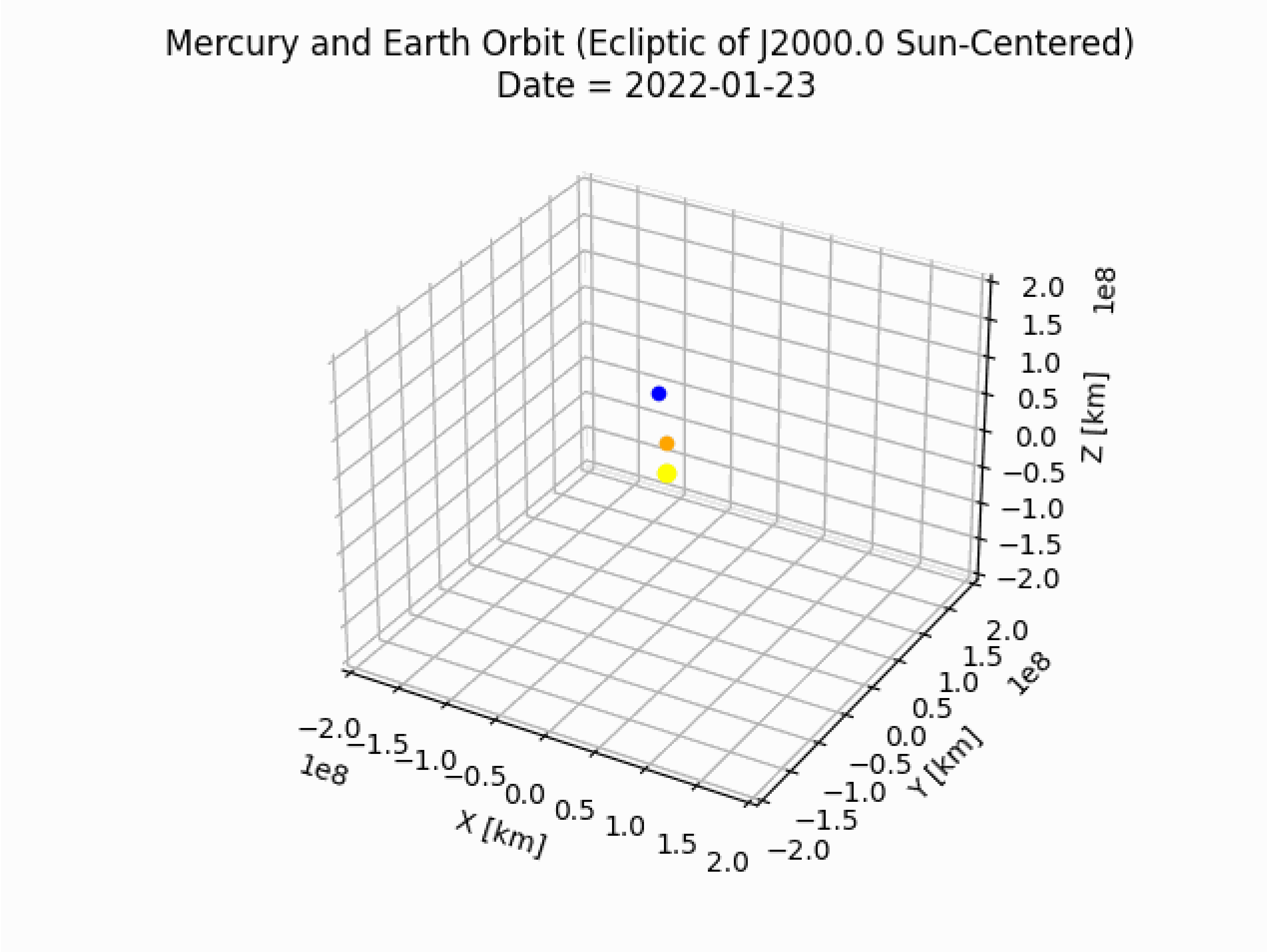
In case you don't read that article, we need initial conditions to solve the equations. If you are trying to recreate the plots at the end of the article, you can use the initial conditions I used (listed below). I used JPL's Horizons System web application (https://ssd.jpl.nasa.gov/horizons/app.html#/) to generate these. You can use different initial conditions, but make sure you are using the Sun as the coordinate system center.

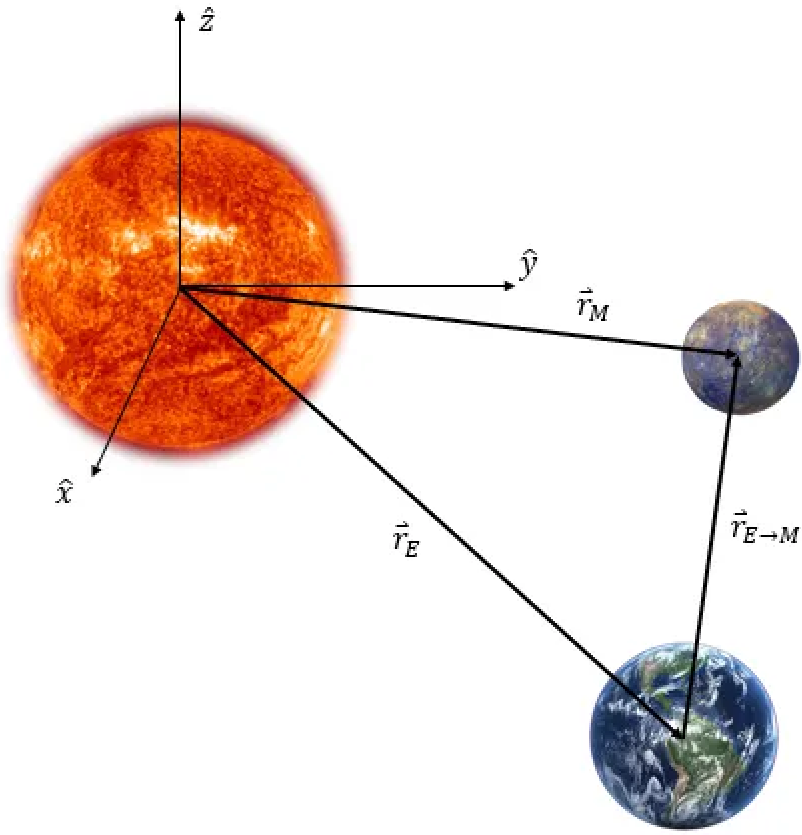
$$
\begin{aligned}
x_{0,E} &= -7.941356415675291E+07\ km & x_{0,M} &= -2.437249751267000E+07\ km \\
y_{0,E} &= 1.239846203914545E+08\ km & y_{0,M} &= 4.124224522405505E+07\ km \\
z_{0,E} &= -6.038695754982531E+03\ km & z_{0,M} &= 5.605858610216193E+06\ km \\
\dot{x}_{0,E} &= -2.556882166045591E+01\ km/s & \dot{x}_{0,M} &= -5.174792569272227E+01\ km/s \\
\dot{y}_{0,E} &= -1.616854116603463E+01\ km/s & \dot{y}_{0,M} &= -2.291721107553359E+01\ km/s \\
\dot{z}_{0,E} &= 1.523728836210658E-03\ km/s & \dot{z}_{0,M} &= 2.873933398403199E+00\ km/s
\end{aligned}
$$

The subscript *E* and *M* stand for Earth and Mercury, respectively. Once we integrate, we will have our results for the position of the planets for the duration of our integration time. This gives us the orbit trajectory (plot below). The blue dot and line represent Earth, the orange dot and line represent Mercury, and the yellow dot represents the Sun. The dates and positions are representative of the actual orbits of Mercury and Earth. They are still approximations due to our assumptions, but as we will see in a second, they are fairly accurate.



Mercury and Earth's Orbits about the Sun [created with Python]

This plot only shows the orbits of the planets from the Sun's perspective, but what we are really interested in is how Mercury moves with respect to the Earth. In other words, what does Mercury look like from the Earth's perspective? We can use a vector to represent this. We already have position vectors for each of Mercury and Earth's orbits (from our integration). Both vectors are with respect to the Sun, so we can subtract them to get our Earth perspective. See the diagram below to visualize what I mean.

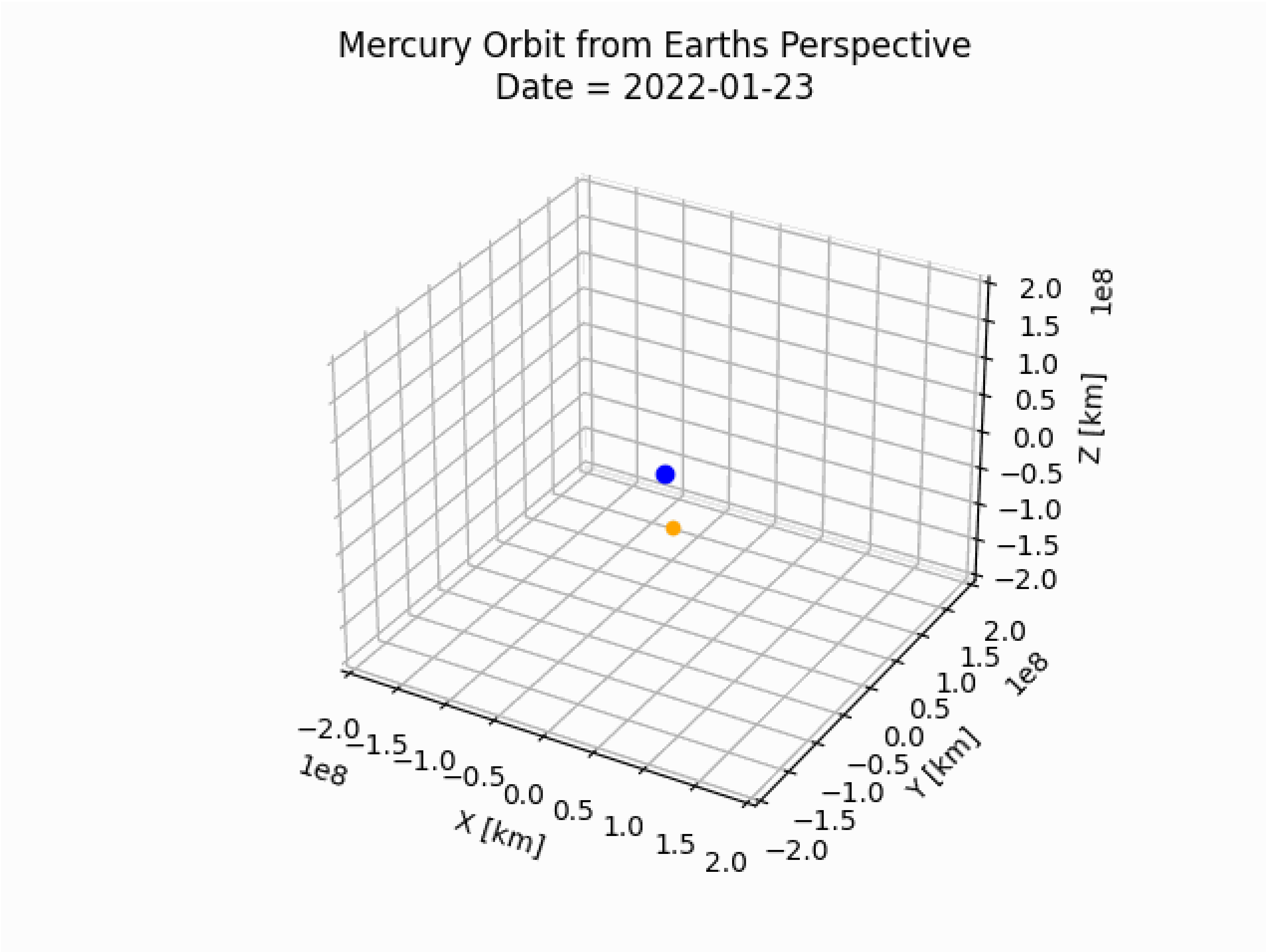


Vector Diagram for Mercury and Earth

We are interested in the vector labeled as *E* to *M*, or Earth to Mercury. This vector represents what we would see if we were at the center of the Earth viewing Mercury (without all of the “earth” being in the way). We can obtain that vector pretty simply:

$$\vec{r}_{E\to M} = \vec{r}_M - \vec{r}_E$$

If we take this new position vector of Mercury with respect to the Earth and plot that for the duration of our integration time, we will get the following:



Mercury's Orbit as an Earth Observer [created with Python]

The blue dot, representing the Earth, will not move in this reference frame since we are now viewing Mercury as an observer on Earth. Mercury, however, will still move, just not as you might expect. You'll notice that the orbit looks different now. There are now about three loops in the orbit. I want you to imagine being on that blue dot and watching Mercury. You'll notice that most of the time, Mercury is moving counter-clockwise… but when it gets to those loops, we momentarily see it move clockwise. This is Mercury retrograde. This is the optical illusion we see on Earth causing our astrology friends to go crazy.

You may have noticed I included the running date on the plots. I did that, so we can check this retrograde motion with online references. If you google

2022 Mercury retrograde dates, you'll see that the loops line up pretty well with what is online. A pretty cool result in my opinion!

If you scrolled to the bottom of the article without reading it, basically, Mercury retrograde refers to a period of time in which Mercury *appears* to move backwards across the sky. Mercury retrograde is simply an optical illusion. Mercury always orbits counterclockwise like the rest of the planets, but, to us, occasionally, it looks like it moves the opposite direction. Sorry astrology lovers, but Mercury retrograde is not actually happening… it just looks like it is.

. . .

Thank you for reading the article! I hope you learned something or just enjoyed it. If you have any questions, feel free to comment and reach out. Leave a clap and follow if you found at least one thing interesting!

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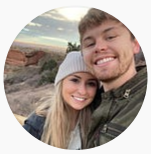

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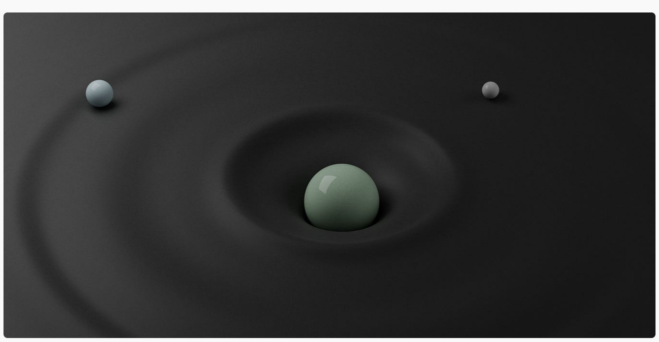

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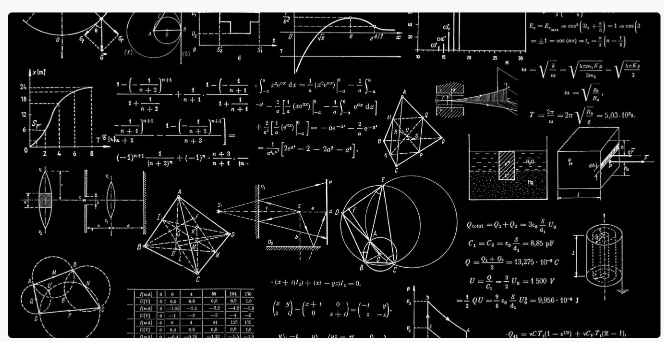

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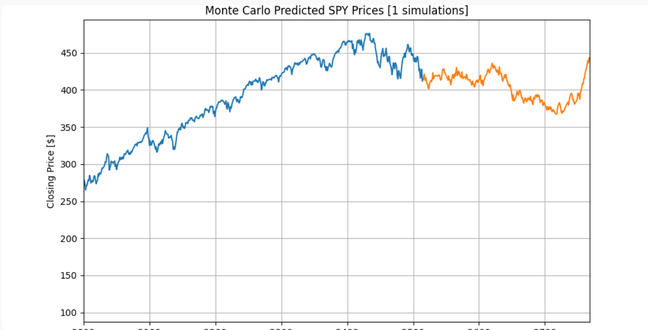

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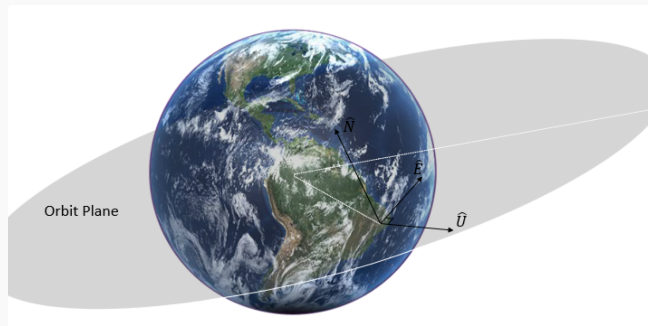

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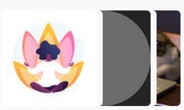

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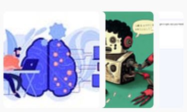

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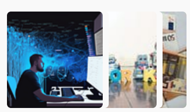

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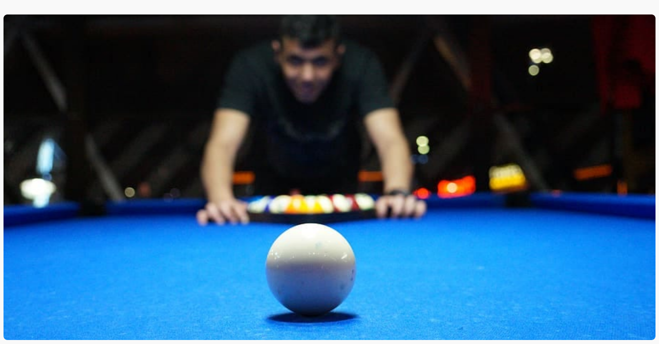

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