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COMPLEX MOVEMENT OF OBJECT

Abstract: *Due to the Cariolis force, objects that fall freely on the Earth's surface during the day are tilted to the east. Due to the slow rotation of the earth, these deviations are very small. In the case of very high-velocity bodies (e.g., rockets and projectiles) or when the motion lasts too long (e.g., rivers in the northern hemisphere wash the right bank, and in the southern hemisphere wash the left bank), this things will be noticeable.*

Key words: *force, slow rotation, movement, solid, cariolis acceleration, average velocity, object, coordinate system.*

Language: *English*

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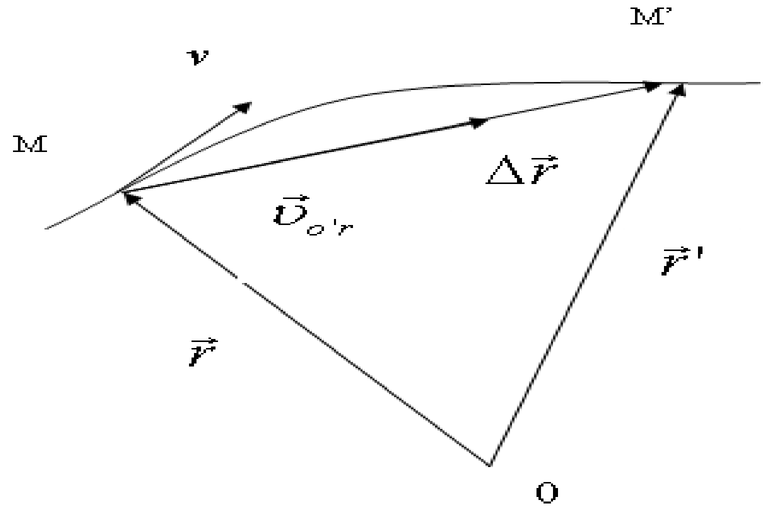
Introduction

Cariolis strength is important in aerospace, meteorology and ballistics. The cariolis force, in turn, causes the cariolis acceleration. By determining the velocity and acceleration of a point in a natural way, we can induce a cariolis acceleration for a complex motion. To do this, we must first determine the velocity of the point in a natural way.

The velocity of an object at the moment in question is called its average velocity.

$$\vec{v}_{o'r} = \frac{\Delta\vec{r}}{\Delta t} \qquad (1)$$

$$\Delta\vec{r} = \Delta\vec{r}'\text{-}\vec{r}$$



The instantaneous velocity of an object is equal to the product of the radius vector and time.

$\vec{v} = \frac{d\vec{r}}{dt} = \dot{\vec{r}}$ (2)

In the coordinate system

$\vec{r} = x\vec{i} + y\vec{j} + z\vec{k}$ (3)

$\vec{v} = \dot{\vec{r}} = \dot{x}\vec{i} + \dot{y}\vec{j} + \dot{z}\vec{k}$ (4)

$v_x = \dot{x}$ $\quad v_y = \dot{y}$ $\quad v_z = \dot{z}$

$v = \sqrt{v_x^2 + v_y^2 + v_z^2}$ $\quad v = \sqrt{x^2 + y^2 + z^2}$ (5)

$\cos(\vec{v}, x) = \frac{v_x}{v}$

$\cos(\vec{v}, y) = \frac{v_y}{v}$ $\quad \cos(\vec{v}, z) = \frac{v_z}{v}$

II.Literature review

To determine the velocity of a point in a natural way, its trajectory must be precise.

On the move

$$\widetilde{MM'} = \Delta S$$

Average speed $\quad v'_{o'r} = \frac{\Delta S}{\Delta t}$

$$v = \lim_{\Delta t \to 0} \frac{\Delta S}{\Delta t} = \frac{dS}{dt}$$

$v'_{o'r} = \frac{\Delta S}{\Delta t}$ $\quad v_{o'r} = \frac{\Delta r}{\Delta t}$ $\quad v'_{o'r} \neq v_{o'r}$

However, the modulus of velocity at the moment Δt → 0 t is equal

$$v = \lim_{\Delta t \to 0} \frac{|\Delta r|}{\Delta t}$$

$$v = v'$$

because

$$v = \lim_{\Delta S \to 0} \frac{|\Delta r|}{\Delta S} = 1$$

We look at the acceleration of the object

$$\Delta\vec{v} = \vec{v}' - \vec{v}$$

$$\vec{a}_{o'r} = \frac{\Delta\vec{v}}{t}$$

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2}$$

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2} = \sqrt{\dot{v}_x^2 + \dot{v}_y^2 + \dot{v}_z^2}$$

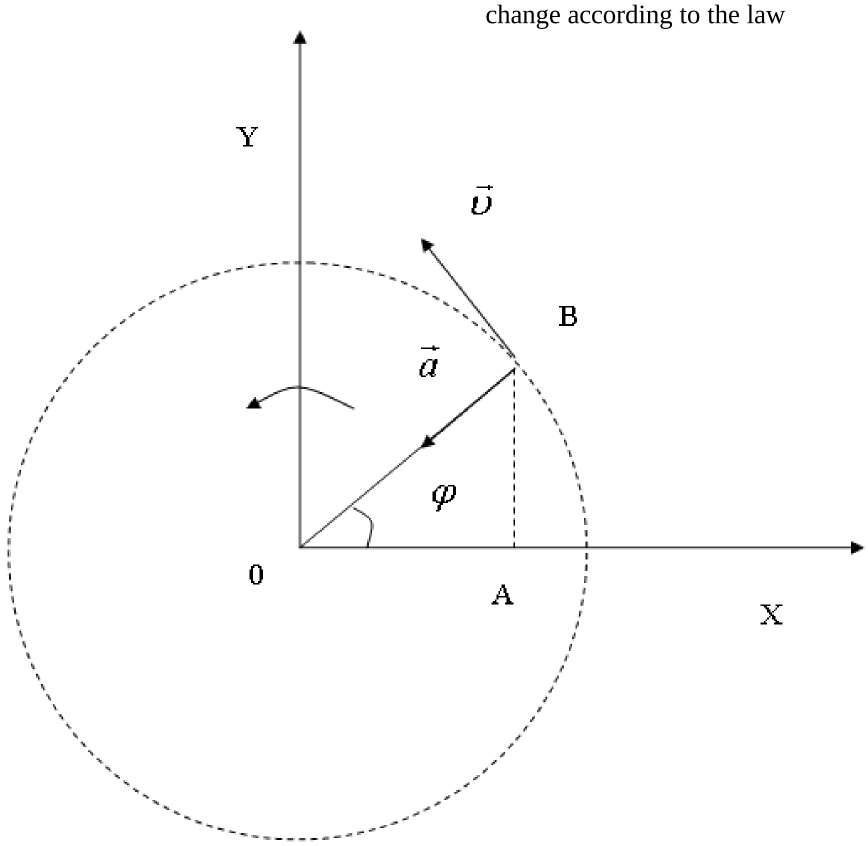
$$= \sqrt{\ddot{x}^2 + \ddot{y}^2 + \ddot{z}^2}$$

$$\vec{a} = a_x\vec{i} + a_y\vec{j} + a_z\vec{k}$$

Let us consider the motion of the B end of the rod relative to the fixed O center

$OB = r$

x angle of rotation relative to $\varphi = \omega t$ will change according to the law



$$x = OA = BO\cos\varphi = r\cos\varphi = r\cos\omega t$$

$$y = BA = \sin\varphi = r\sin\varphi = r\sin\omega t$$

$$v_x = \frac{dx}{dt} = -r\omega\sin\omega t$$

$$v_y = \dot{y} = r\omega\cos\omega t$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{(-r\omega\sin\omega t)^2 + (r\omega\cos\omega t)^2}$$

$v = r\omega = const$ the speed module is constant $\omega = const$

Let's find the direction

$$\cos(\vec{v},x)=\frac{v_x}{v}=-\frac{r\omega\sin\omega t}{\omega r}=\sin\varphi$$
$$\cos(\vec{v},y)=\frac{v_y}{v}=\frac{r\omega\cos\omega t}{\omega r}=\cos\varphi$$

Acceleration projections

$$a_x=\dot{v}_x=-r\omega^2\cos\omega t$$
$$a_y=\dot{v}_y=-r\omega^2\sin\omega t$$
$$a=\sqrt{a_x^2+a_y^2}=-r\omega^2\cos\omega t=const$$
$$a=r\omega^2$$

Although the modulus of velocity is constant, the modulus of acceleration is different from zero. Because the trajectory is curved, the direction of velocity is constantly changing.

III.Analysis

Acceleration direction

$$\cos(\vec{a},x)=\frac{a_x}{a}=\frac{-r\omega^2\cos\omega t}{r\omega^2}=-\cos\omega t$$
$$=-\cos\varphi$$
$$\cos(\vec{a},y)=\frac{a_y}{a}=-\sin\omega t=\sin\varphi$$

$\vec{a}$ is directed to the center of rotation

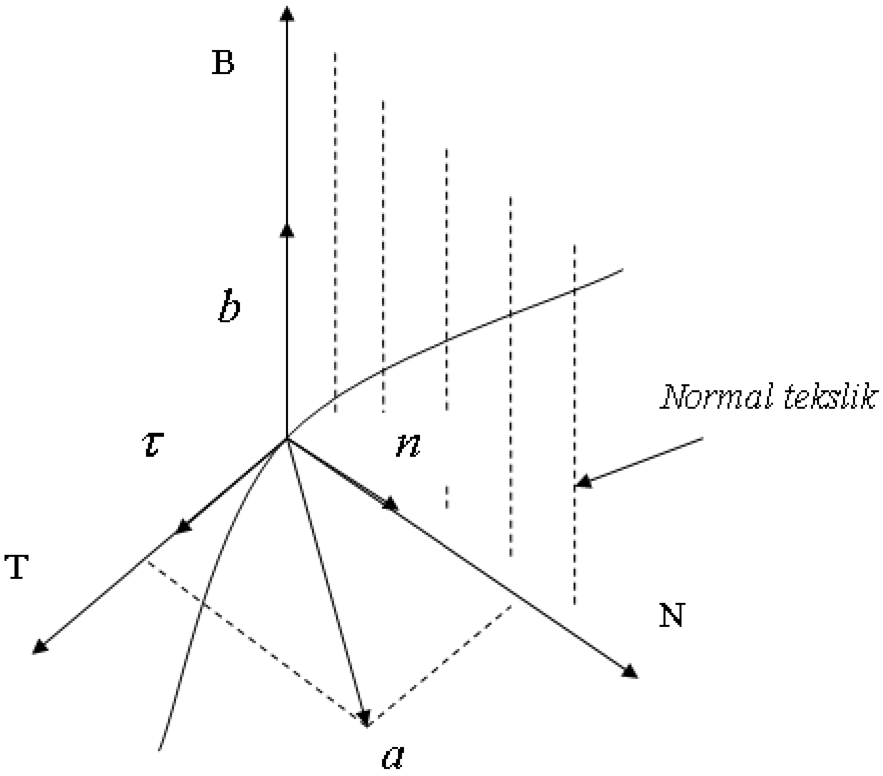
$$t=0$$
$$\cos(\vec{a},x)=-1$$
$$\cos(\vec{a},y)=0 \qquad \vec{a},\hat{}\ x=\pi \qquad \vec{a},\hat{}\ y=\frac{\pi}{2}$$
$$t=\frac{\pi}{2\omega}$$
$$\cos(\vec{a},x)=0$$
$$\cos(\vec{a},y)=-1 \qquad \vec{a},\hat{}\ x=\frac{\pi}{2} \qquad \vec{a},\hat{}\ y=\pi$$
$$t=0$$
$$\cos(\vec{v},x)=0$$
$$\cos(\vec{v},y)=1 \qquad \vec{v},\hat{}\ x=\frac{\pi}{2} \qquad \vec{v},\hat{}\ y=0$$

Determination of point acceleration in a natural way. If the motion of a point is given in a natural way, the acceleration is divided into components.

The tangent plane is perpendicular to the normal plane. MN is head normal, MB is binormal. Unity vectors $\vec{c}$- experiment, $\vec{n}$- normal, $\vec{b}$- binormal.

We express the vector $\vec{a}$ on the natural coordinate axes

$$\vec{a}=a_\tau\vec{\tau}+a_n\vec{n}+a_b\vec{b} \qquad (6)$$

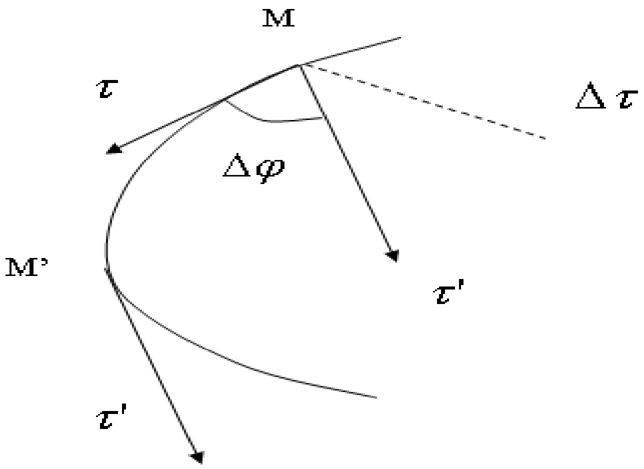


Because the vector $\vec{v}$ of the point is always directed to the trajectory

$$\vec{v}=v\vec{\tau} \qquad (7)$$

We can derive two variables.

$$\vec{a}=\frac{d\vec{v}}{dt}=\vec{\tau}\frac{dv}{dt}+v\frac{d\vec{\tau}}{dt}$$
$$|\Delta\tau|=2|\tau|\sin\frac{\Delta\varphi}{2}=2\sin\frac{\Delta\varphi}{2}$$
$$|\Delta\tau|=1$$



$$\left|\frac{d\tau}{dt}\right| = \lim_{\Delta t\to 0}\left|\frac{\Delta\tau}{\Delta t}\right| = \lim_{\Delta t\to 0}\frac{2\sin\frac{\Delta\varphi}{2}}{\Delta t} = \lim_{\Delta t\to 0}\left(\frac{\sin\frac{\Delta\varphi}{2}}{\frac{\Delta\varphi}{2}}\times\frac{\Delta\varphi}{\Delta S}\times\frac{\Delta S}{\Delta t}\right)$$

$$\Delta S = \widetilde{MM'}$$

If $\Delta t \to 0$ $\quad \Delta S \to 0$ $\quad \Delta\varphi \to 0$

$$\left|\frac{d\tau}{dt}\right| = \lim_{\Delta\varphi\to 0}\frac{2\sin\frac{\Delta\varphi}{2}}{\Delta t}\times\lim_{\Delta S\to 0}\frac{\Delta\varphi}{\Delta S}\times\lim_{\Delta t\to 0}\frac{\Delta S}{\Delta t}$$

The first limit is 1

$$\lim_{\Delta t\to 0}\frac{\Delta S}{\Delta t} = \frac{dS}{dt} = v$$

$$\lim_{\Delta S\to 0}\frac{\Delta\varphi}{\Delta S} = k = \frac{1}{\rho} \qquad (8)$$

k-line curvature, ρ-. curvature radius.

$$\left|\frac{d\tau}{dt}\right| = \frac{v}{\rho} \qquad \frac{d\vec{\tau}}{dt}$$

The direction of the vector is normal to the head.

$$\vec{a} = \frac{dv}{dt}\vec{\tau} + \frac{v^2}{\rho}\vec{n} \qquad (9)$$

$$a_\tau = \frac{dv}{dt} \qquad a_n = \frac{v^2}{\rho} \qquad a_b = 0 \qquad (10)$$

Hence the acceleration $\vec{a}$ lies in the tangent plane and can be divided into two components:

$a_\tau -$ effort or tangential acceleration.

$a_n -$ normal acceleration

$$a = \sqrt{a_\tau^2 + a_n^2} = \sqrt{\left(\frac{dv}{dt}\right)^2 + \left(\frac{v^2}{\rho}\right)^2} \qquad (11)$$

$$\cos(a, a_\tau) = \frac{a_\tau}{a}$$

$$\cos(a, a_n) = \frac{a_n}{a} \qquad (12)$$

Here are some special cases:

1. Smooth movement

$$v = \frac{dS}{dt} = const$$

$$\vec{a} = \frac{dv}{dt}\vec{\tau} + \frac{v^2}{\rho}\vec{n} = \frac{v^2}{\rho}\vec{n}$$

$$a_n = \frac{v^2}{\rho} \qquad a_\tau = \frac{dv}{dt} = 0$$

$$a = a_n = \frac{v^2}{\rho} \qquad (13)$$

IV.Discussion

Only a change in speed is characteristic.

1. Linear motion.

In a linear motion, the radius of curvature of the trajectory is $\rho = \infty$ and

$$a_n = \frac{v^2}{\rho} = 0.$$

$$\vec{a} = \frac{dv}{dt}\vec{\tau} + \frac{v^2}{\rho}\vec{n} = \frac{dv}{dt}\vec{\tau}$$

$$a = a_\tau = \frac{dv}{dt} \qquad (14)$$

If there is a straight line

$$\frac{dv}{dt} = 0 \qquad \frac{v^2}{\rho} = 0$$

a = 0 object has no acceleration.

3.Smooth accelerating motion.

$$\vec{a} = \frac{dv}{dt}\vec{\tau} + \frac{v^2}{\rho}\vec{n}$$

The change in the algebraic value of the velocity is characterized by the acceleration a_τ

$$v = v_0 + a_\tau t \qquad (15)$$

$$S = v_0 t + \frac{a_\tau t^2}{2} \qquad (16)$$

These formulas are suitable for both straight and curved movements

4. Harmonic oscillations.

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As for the beginning of the calculation as harmonic oscillations $S = a\sin\omega t$ or

$S = a\cos\omega t$ (17)

variable actions under the law $.a > 0,$

ω- constant magnitude .Function functions change from 1 to -1

$-a \le S \le a.$

a-amplitude, $\omega - 2\pi$ the number of oscillations per second. Full vibration period.

$$\omega(\tau + T) = \omega\tau + 2\pi$$

$$T = \frac{2\pi}{\omega} \qquad (18)$$

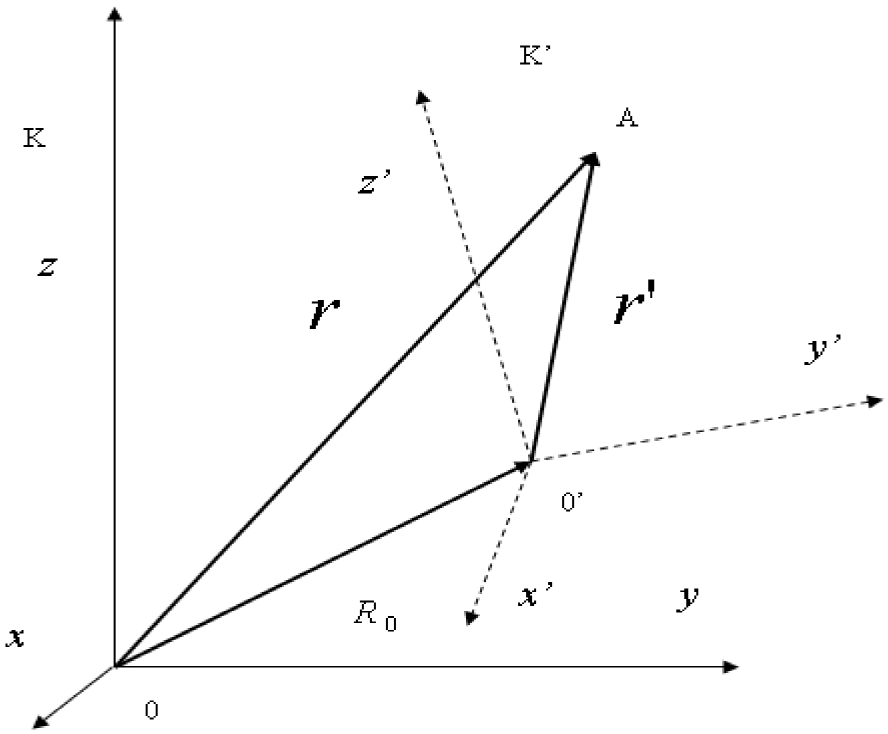
ω- the rotational frequency of the vibration.

Advanced movement speed. The motion of a point with respect to a system assumed to be stationary is called absolute motion. $\vec{v}, \vec{a}$

The motion of a point with respect to a moving system is called relative motion.v_r, a_r

The motion of a system relative to a system that is assumed to be stationary at all points is called forward motion. $\vec{a}_R, \vec{v}_R$

Let the point move with respect to the moving system k' and the stationary k.



$\vec{r} = \vec{R}_0 + \vec{r}'$ (19)

If we harvest in time

$$\frac{d\vec{r}}{dt} = \frac{d\vec{R}_0}{dt} + \frac{d\vec{r}'}{dt}$$

$\vec{v} = \vec{v}_R + \vec{v}_r$ (20) in this

$$\vec{v}_r = \frac{d\vec{r}'}{dt} = \frac{dx'}{dt}\vec{\imath}' + \frac{dy'}{dt}\vec{\jmath}' + \frac{dz'}{dt}\vec{k}' \qquad (21)$$

The relative velocity of a point or k' is the velocity in the system

$$\vec{R}_0 = \vec{r}_0 + x'\vec{\imath}' + y'\vec{\jmath}' + z'\vec{k}'$$

$$\vec{v}_R = \frac{d\vec{R}_0}{dt} = \frac{d\vec{r}_0'}{dt} + x'\frac{d\vec{\imath}'}{dt} + y'\frac{d\vec{\jmath}'}{dt} + z'\frac{d\vec{k}'}{dt} \qquad (22)$$

$\vec{R}_0 - x', y', z' - const$ the radius vector of a point when it is constant. $\vec{r}_0 -$ radius vector characterizing the center of mass of the object.

$$\vec{v} = \frac{d\vec{r}}{dt} = \left(\frac{d\vec{r}_0'}{dt} + x'\frac{d\vec{\imath}'}{dt} + y'\frac{d\vec{\jmath}'}{dt} + z'\frac{d\vec{k}'}{dt}\right) + \left(\frac{d\vec{r}_0'}{dt} + \frac{dx'}{dt}\vec{\imath}' + \frac{dy'}{dt}\vec{y}' + + \frac{dz'}{dt}\vec{k}'\right) \qquad (23)$$

The absolute velocity of a point.

From the last formula (23) we can derive $\vec{\imath}', \vec{\jmath}', \vec{k}'$ and x', y', z' as variable quantities for absolute acceleration.

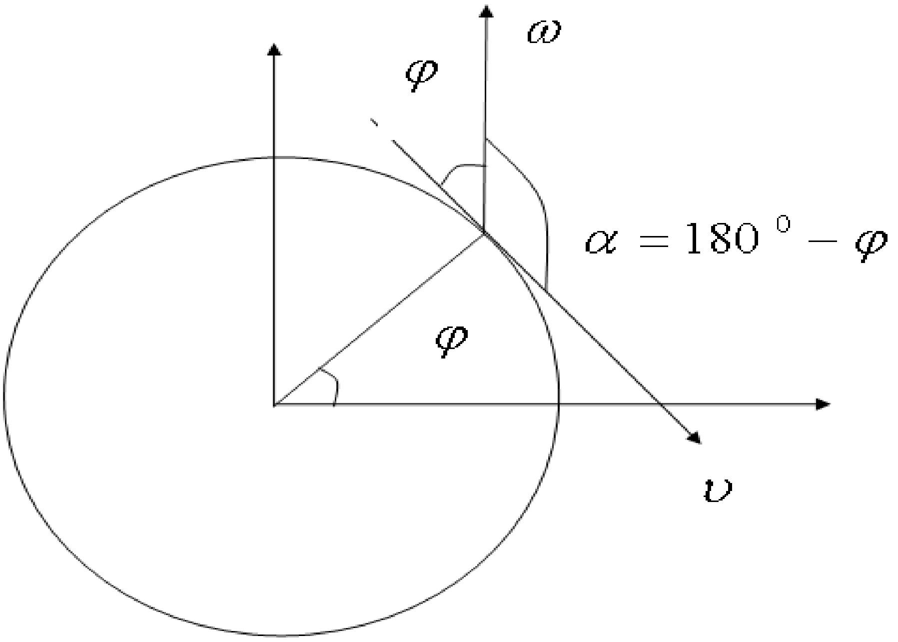
$$\vec{a} = \vec{a}_R + \vec{a}_r + \vec{a}_k \qquad (24)$$

$\vec{a}_R -$ rotational acceleration (cariolis acceleration)

$\vec{a}_r -$ relative acceleration of a point

$$\vec{a}_k = 2\left(\frac{dx'}{dt}\frac{d\vec{\imath}'}{dt} + \frac{dy'}{dt}\frac{d\vec{\jmath}'}{dt} + \frac{dz'}{dt}\frac{d\vec{k}'}{dt}\right) \qquad (25)$$

Hence, the acceleration of a point in a complex motion is equal to the sum of its rotational acceleration, relative acceleration, and cariolis acceleration.



Of course

$$\vec{v} = [\vec{\omega}, \vec{r}] = \frac{d\vec{r}}{dt}$$

The rotation is in motion or

$$\frac{d\vec{\imath}'}{dt} = [\vec{\omega}, \vec{\imath}'], \quad \frac{d\vec{\jmath}'}{dt} = [\vec{\omega}, \vec{\jmath}'], \quad \frac{d\vec{k}'}{dt} = [\vec{\omega}, \vec{k}']$$

Considering the caryolis acceleration using the vector multiplication formula

$$\vec{a}_k = 2[\vec{\omega} \times \vec{v}_r] \qquad (26)$$

It's a module

$$\vec{a}_k = 2\omega\vec{v}_r \sin(\vec{\omega} \times \vec{v}_r) \qquad (27)$$

Hence, the karyolytic acceleration of a point in complex motion is equal to the vector product of the relative velocity of the point and the angular velocity at a given moment of the excited *Oxyz* coordinate system.

For example, a point moving from north to south along the meridian with velocity $\vec{v}_r = 100\frac{m}{s}$ is affected by an acceleration to the east at a_k = 1.26cm/s at latitude $\alpha = 60^{\circ}$.

$\left(\omega_y = 0.0000727\frac{rad}{s}\right)$ the angular velocity of the earth.

This formula can be used to solve problems related to the complex motion of a point as above.

V.Conclusion

In special cases, the given formulas can be used in the formation of knowledge, skills and competencies on the topic of types of mechanical movement in the 10th grade physics of secondary schools. The formulas are given ready. High mastery can be achieved when working with gifted students and explaining the essence of the topic by quoting formulas for high-achieving students in the classroom.

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