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The Rotundity of Large Planetary Objects

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THE ROTUNDITY OF LARGE PLANETARY OBJECTS

ADESANWO MORADEYO

Department of Physics

APPROVED:

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Jorge A. L´opez, Ph.D., Chair

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Harold Slusher, Ph.D.

____
Charles H. Ambler, PH.D

Dean of the Graduate School

DEDICATION

To my late great grand father and all my mentors

THE ROTUNDITY OF LARGE PLANETARY OBJECTS

By

ADESANWO MORADEYO, B.S.

PROJECT

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

Department of Physics

THE UNIVERSITY OF TEXAS AT EL PASO

December 2004.

ACKNOWLEDGEMENTS

First and foremost, I want to thank God for giving me the opportunity to still be alive and for seeing me through this project and my master degree program in this University. I would like to thank my family for their support and encouragement,

I also want to thank my supervisor, Dr. Harold Slusher for his support

and assistance. I acknowledge the members of the committee, Dr. Jorge L´opez for taking his time to serve on my project committee and I also want to thank my brothers and sisters, all my friends i.e. my classmate of the Physics Department, friends at home,America,England,Africa for their love and affections.

December, 2004 Adesanwo Moradeyo

ABSTRACT

The most obvious structural feature of planetary bodies is their roundness. This arises because of the dominate roles of the two effects of gravity and case of the deformation of matter, whether gas, liquid or solid. This project is about proving and solving out the time scale (τ) of flow restoring the body to spherical shape when we consider a slightly deformed self-gravitating sphere and also checking for spherical of different planetary objects.

TABLE OF CONTENT

CHAPTER ONE

1. Proving the Time Scale Equation

The theory of the gravitational oscillation of a mass of liquid about the spherical form is due to Kelvin. If we take the origin at the centre and denoting the radius vector at any point of the surface by a+ζ i.e. where a is the radius in the undisturbed state.

We assume $$\zeta = \sum_{1}^{\infty} \varsigma_n \cdots\cdots\cdots (i)$$

Where ζ_n is a surface-harmonic of integral order n.

The ideal fluid continuity equation is $\nabla^2 \phi = 0$ i.e.

$$\theta = \nabla . q = 0$$

$$\partial\phi = \frac{\partial\phi}{\partial x}\partial x + \frac{\partial\phi}{\partial y}\partial y + \frac{\partial\phi}{\partial z}\partial z$$

where $u = \frac{\partial\phi}{\partial x}$ $v = \frac{\partial\phi}{\partial y}$ $w = \frac{\partial\phi}{\partial z}$

the velocity leads to the Laplace equation in the velocity potential

$$\nabla . \nabla\phi = \nabla^2 \phi = 0$$

The potential for all possible irrotational motions of an incompressible fluid must satisfy the Laplace equation, most ideal fluid motions are irrotational, since rotation must commonly arises through the action of viscosity (friction).

$$\nabla.q = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

therefore the equation of continuity is satisfied by

$$\phi = \sum_{1}^{\infty} \frac{r^n}{a_n} s_n \cdots\cdots\cdots (ii)$$

where s_n is a surface-harmonic and kinematical conditions,

$$\frac{\partial \varsigma}{\partial t} = -\frac{\partial \phi}{\partial r} \cdots\cdots\cdots (iii)$$

$$\frac{\partial \phi}{\partial r} = \sum_{1}^{\infty} \frac{nr^{n-1}}{a_n} S_n$$

$$\frac{\partial \phi}{\partial r} = \sum_{1}^{\infty} \frac{nr^{n-1}}{a_n} S_n$$

Therefore to be satisfied when r = a gives

$$\frac{\partial \varsigma_n}{\partial t} = -\frac{n}{a} s_n \cdots\cdots\cdots (iv)$$

The gravitational potential at the free surface is

$$\Omega = -\frac{4\pi\gamma\rho a^3}{3r} - \sum_1^\infty \frac{4\pi\gamma\rho a}{2n+1}\zeta_n \cdots\cdots\cdots(v)$$ Where γ is the gravitational constant.

Putting g = $\frac{4}{3}\pi\gamma a$, $r = a + \Sigma\varsigma_n$

Resolving the gravitational potential

$$\Omega = cons\tan t + g\sum_1^\infty \frac{2(n-1)}{2n+1}\varsigma_n \cdots\cdots\cdots(vi)$$

substituting from (ii) and (v) in the pressure equation

$$\frac{p}{\rho} = \frac{\partial\phi}{\partial t} - \Omega + cons\tan t \cdots\cdots\cdots(vii)$$

since P must be constant over the surface

$$\frac{\partial\varsigma_n}{\partial t} = \frac{2(n-1)}{2n+1} g\varsigma_n \cdots\cdots\cdots(viii)$$

Eliminating S_n between (vii) and (viii) we have

$$S_n = -\frac{a}{n}\frac{\partial\varsigma_n}{\partial t}$$

$$\frac{\partial^2\varsigma_n}{\partial t^2} = -\frac{n}{a}\frac{2(n-1)}{2n+1} g\varsigma_n \cdots\cdots\cdots(ix)$$

therefore this shows that $\varsigma_n \propto \cos(\sigma_n t + \varepsilon)$,where we have

$$\sigma_n{}^2 = \frac{2n(n-1)}{2n+1}\frac{g}{a}\cdots\cdots\cdots(x)$$

for the same density of liquid $g\alpha$ a and the frequency is therefore independent of the dimensions of the globe.

If n = 1, i.e. $\sigma = 0$ since in a small deformation expressed by a surface-harmonic of the first order the surface remains spherical and the period is therefore infinitely long.

In case of a highly viscous globe returning asymptotically to the spherical form under the influence of gravitation, the velocity potential is in the form

$$\phi = A\frac{r^{n+1}}{a^{n+1}}s_n.\cos(\sigma t+\varepsilon)\cdots\cdots\cdots(xi)$$

i.e. s_n is a the surface harmonic.

Therefore the kinetic energy included within a sphere of radius r, we have the expression in the form

$$\rho\iint\phi\frac{\partial\phi}{\partial r}r^2\partial\varpi = \rho(n+1)\frac{r^{2n+2}}{a^{2n+2}}\iint s_n{}^2\partial\varpi.A^2\cos^2(\sigma t+\varepsilon)\cdots\cdots\cdots(xii)$$

since we are dealing with the spherical form under the influence of gravitation the total kinetic energy

$$T = \frac{1}{2}\rho gna\iint s_n{}^2\partial\varpi.A^2\cos^2(\sigma t+\varepsilon)\cdots\cdots\cdots(xiii)$$

and potential energy is

$$v = \frac{1}{2}\rho gna\iint s_n{}^2\partial\varpi.A^2\sin^2(\sigma t+\varepsilon)\cdots\cdots\cdots(xiv)$$

Total Energy = T + V

$$=\frac{1}{2}\rho gna\iint {s_n}^2\partial\varpi.A^2\cos^2(\sigma t+\varepsilon)+\frac{1}{2}\rho gna\iint {s_n}^2\partial\varpi.A^2\sin^2(\sigma t+\varepsilon)$$

$$T+V=\frac{1}{2}\rho gna\iint {s_n}^2\partial\varpi.A^2\cdots\cdots\cdots(xv)$$

again, the dissipation in a sphere of radius r, calculated on the assumption that the motion is irrotational under the gravitational influence,

$$\mu\iint\frac{\partial.q^2}{\partial r}r^2\partial\varpi=\mu r^2\frac{\partial}{\partial r}\iint q^2\partial\varpi$$

$$r^2\iint q^2\partial\varpi=\frac{\partial}{\partial r}\iint\phi\frac{\partial\phi}{\partial r}r^2\partial\varpi$$

and $$\iint\phi\frac{\partial\phi}{\partial r}r^2\partial\varpi=\rho(n+1)\frac{r^{2n+2}}{a^{2n+2}}\iint {s_n}^2\partial\varpi.A^2\cos^2(\sigma t+\varepsilon)$$

$$=\rho(n+1)2(n+1)\frac{r^{2n+1}}{a^{2n+2}}\iint {s_n}^2\partial\varpi$$

putting r = a, we have for the total dissipation

$$2F=\left(\rho2(n+1)^2+1\right)\mu\iint {s_n}^2\partial\varpi.A^2\cos^2(\sigma t+\varepsilon)\cdots\cdots\cdots(xvi)$$

therefore, if the effects of inertia being disregarded and also if the effect of viscosity be represented by a gradual variation of the coefficient A,we have

$$\frac{\partial}{\partial t}(T+V)=2F\cdots\cdots\cdots(xvii)$$

The mean value of which, per unit time is

$$2\overline{F}=\rho(n+1)^2+1.\mu\iint s_n{}^2\partial\varpi.A^2$$

$$\frac{\partial}{\partial t}\left(\frac{1}{2}\rho gna\iint s_n{}^2\partial\varpi.A^2\right)=\rho(n+1)+1.\mu\iint s_n{}^2\partial\varpi.A^2$$

$$\frac{\partial A}{\partial t}=\frac{2(n+1)^2+1}{n}\frac{\nu}{ga}A\cdots\cdots\cdots(xviii)$$

from equation $(xviii)$,we can shew $A\alpha\ell^{-\frac{t}{\tau}}$ and $\frac{\partial A}{\partial t}=\tau\rightarrow$ time scale or time interval;

$$\tau=\frac{2(n+1)^2+1}{n}\frac{\nu}{ga}\cdots\cdots\cdots(xix)$$

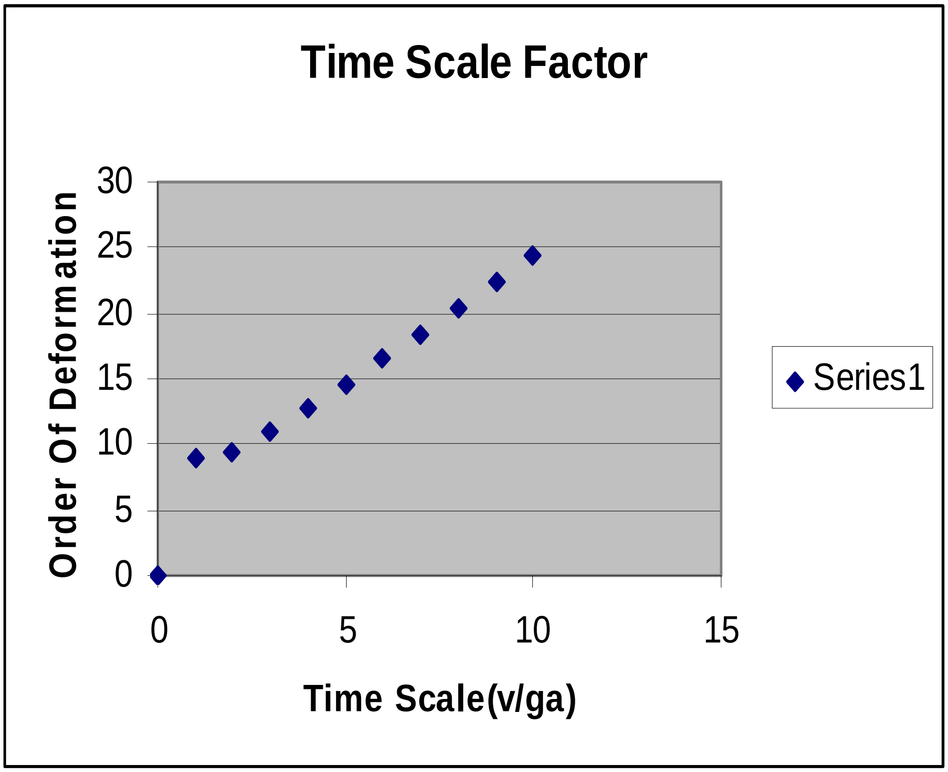
where n is the order of deformation, ν is the kinematic viscosity is the acceleration due to gravity

From the time scale or time interval, checking for different values of n, where n is the order of the deformation (of surface wavelength $\frac{2\pi a}{n}$)

$$\tau=\frac{2(n+1)^2+1}{n}\frac{\nu}{ga}$$

We can check different values of n and plot the time scale τ against the order of deformation and vice versa.

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$
0	$0\left(\frac{\nu}{ga}\right)$
1	$9\left(\frac{\nu}{ga}\right)$
2	$9.5\left(\frac{\nu}{ga}\right)$
3	$11\left(\frac{\nu}{ga}\right)$
4	$12.75\left(\frac{\nu}{ga}\right)$
5	$14.6\left(\frac{\nu}{ga}\right)$
6	$16.5\left(\frac{\nu}{ga}\right)$
7	$18.43\left(\frac{\nu}{ga}\right)$
8	$20.375\left(\frac{\nu}{ga}\right)$
9	$22.33\left(\frac{\nu}{ga}\right)$
10	$24.3\left(\frac{\nu}{ga}\right)$


Time Scale Factor
Order Of Deformation
30
25
20
15
10
5
0
0
5
10
15
Time Scale(v/ga)
Series1

We can calculate the time scale τ ,for different values of (a) using the different values of (n).For a typical material of density $3000\,kg/m^3$

and kinematic viscosity $\nu = 10^{17} m^2/s$ and for values of a = 1,100,,200,300,400,500 and 1000km.

Kinematic viscosity is defined as the dynamic viscosity divided by density,

$$\nu = \frac{\eta}{\rho} = 10^{17} m^2/s$$

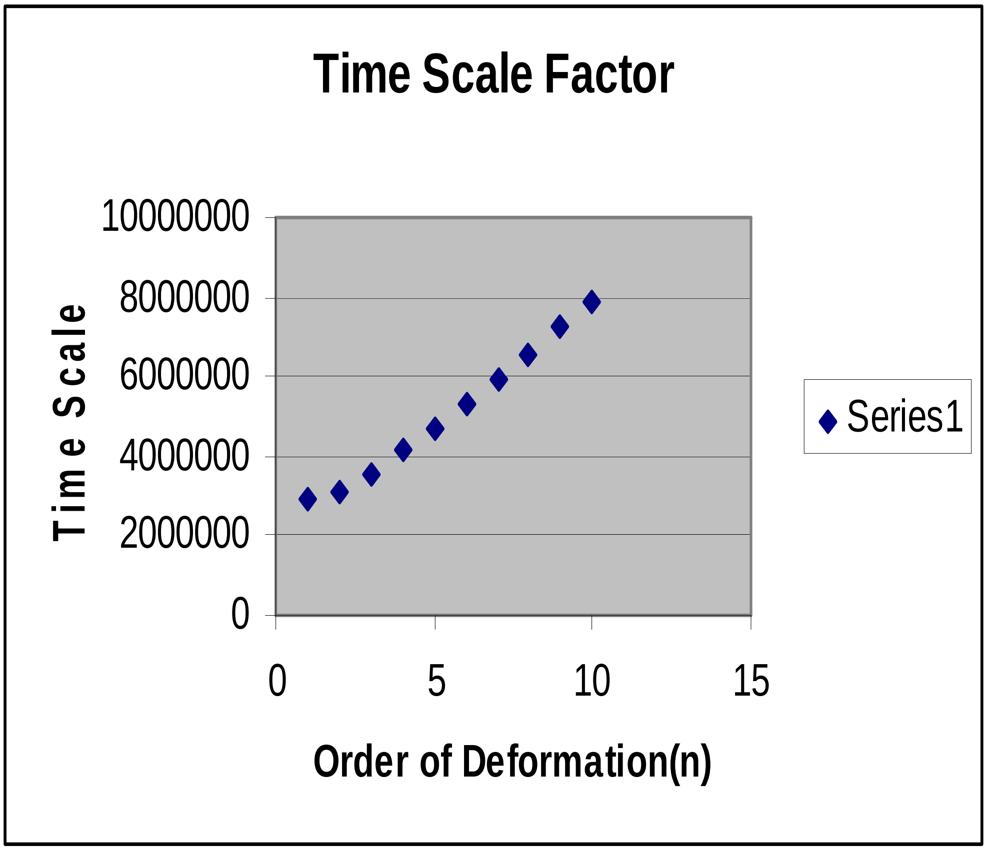
And the acceleration due to gravity $g = 9.8m/s^2$

CASE 1.

For $a = 1km, \nu = 10^{17} m^2 / s, g = 9.8m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	2.9×10^6 *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	3.1×10^6 *years*
3	$11\left(\frac{\nu}{ga}\right)$	3.6×10^6 *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	4.1×10^6 *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	4.7×10^6 *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	5.3×10^6 *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	6.0×10^6 *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	6.6×10^6 *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	7.2×10^6 *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	7.9×10^6 *years*

Graph showing the plot of Time Scale against the Order of Deformation

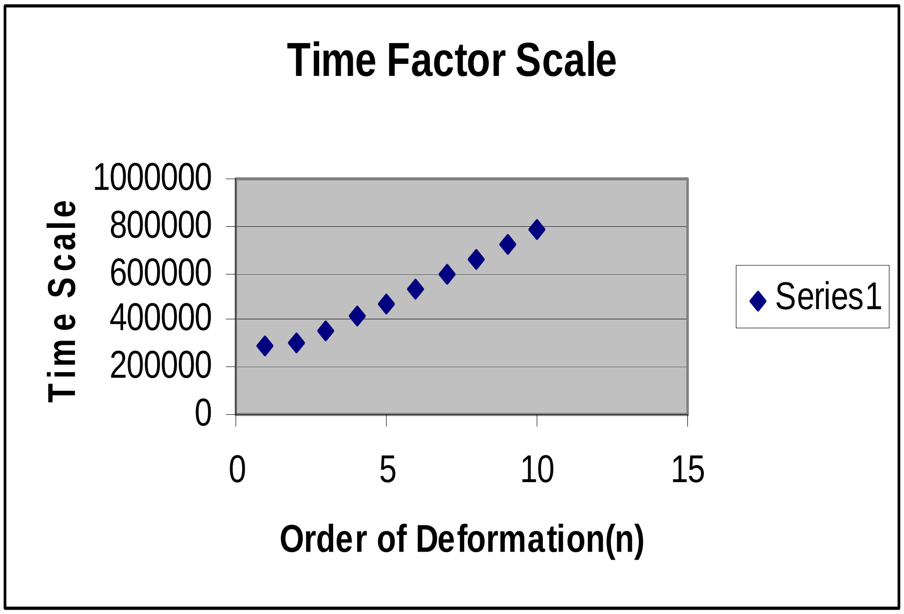


CASE 2.

For $a = 10km, \nu = 10^{17} m^2 / s, g = 9.8 m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	$0\ years$
1	$9\left(\frac{\nu}{ga}\right)$	$2.9\times10^5\ years$
2	$9.5\left(\frac{\nu}{ga}\right)$	$3.1\times10^5\ years$
3	$11\left(\frac{\nu}{ga}\right)$	$3.6\times10^5\ years$
4	$12.75\left(\frac{\nu}{ga}\right)$	$4.1\times10^5\ years$
5	$14.6\left(\frac{\nu}{ga}\right)$	$4.7\times10^5\ years$
6	$16.5\left(\frac{\nu}{ga}\right)$	$5.3\times10^5\ years$
7	$18.43\left(\frac{\nu}{ga}\right)$	$6.0\times10^5\ years$
8	$20.375\left(\frac{\nu}{ga}\right)$	$6.6\times10^5\ years$
9	$22.33\left(\frac{\nu}{ga}\right)$	$7.2\times10^5\ years$
10	$24.3\left(\frac{\nu}{ga}\right)$	$7.9\times10^5\ years$

Graph showing the plot of Time Scale against the Order of Deformation

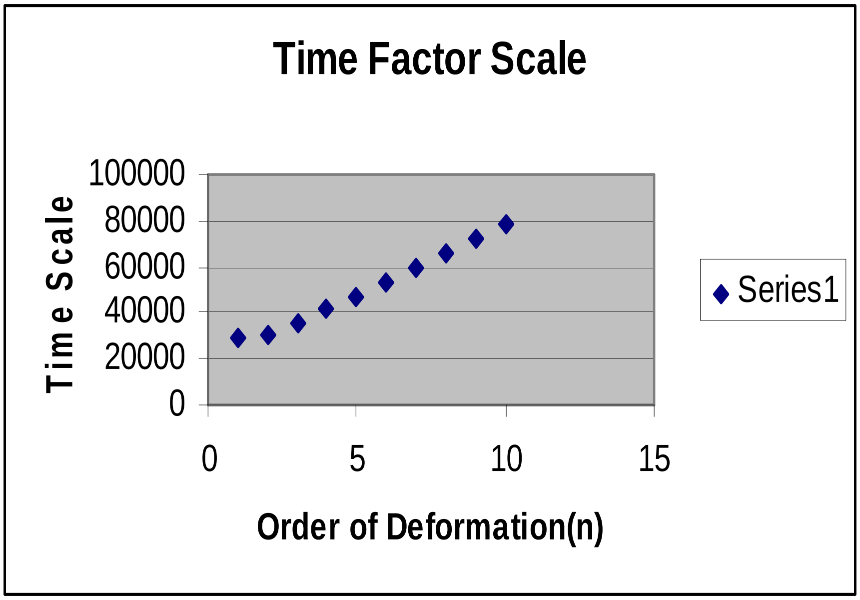


CASE 3.

For $a = 100km, \nu = 10^{17} m^2 / s, g = 9.8m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	2.9×10^4 *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	3.1×10^4 *years*
3	$11\left(\frac{\nu}{ga}\right)$	3.6×10^4 *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	4.1×10^4 *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	4.7×10^4 *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	5.3×10^4 *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	6.0×10^4 *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	6.6×10^4 *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	7.2×10^4 *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	7.9×10^4 *years*

Graph showing the plot of Time Scale against the Order of Deformation

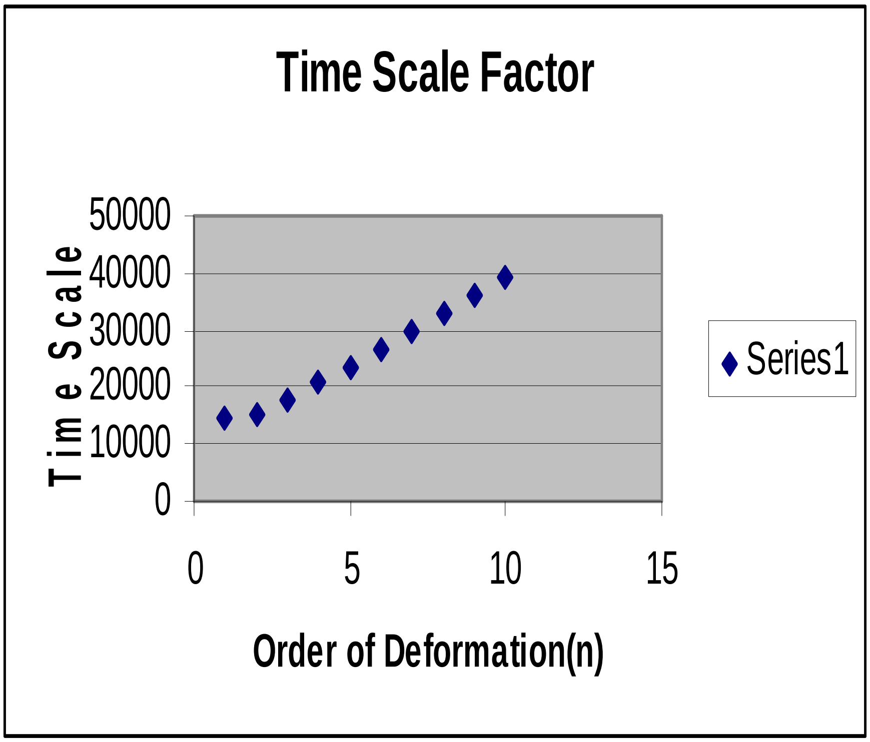


CASE 4.

For $a = 200km, \nu = 10^{17} m^2/s, g = 9.8m/s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	1.5×10^4 *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	1.54×10^4 *years*
3	$11\left(\frac{\nu}{ga}\right)$	1.8×10^4 *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	2.1×10^4 *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	2.4×10^4 *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	2.7×10^4 *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	3.0×10^4 *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	3.3×10^4 *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	3.6×10^4 *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	3.9×10^4 *years*

Graph showing the plot of Time Scale against the Order of Deformation

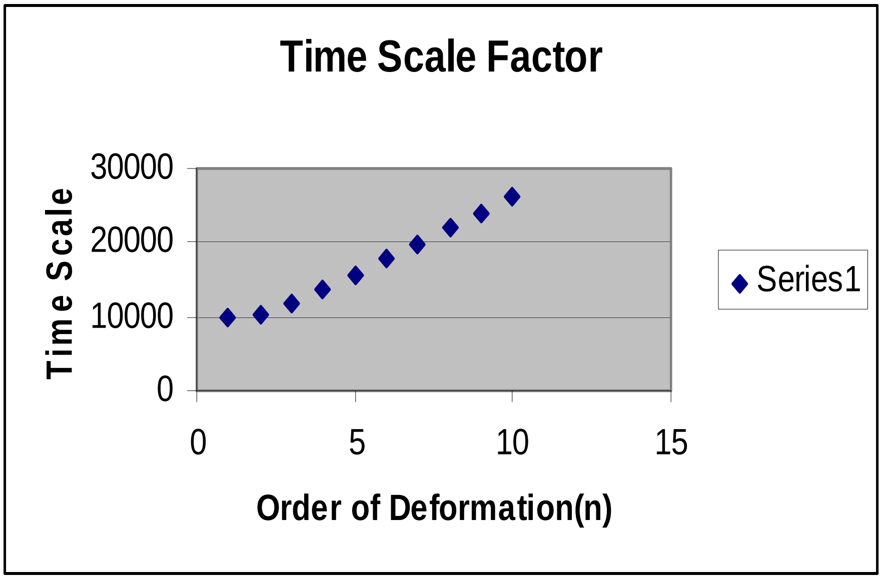


CASE 5.

For $a = 300km, \nu = 10^{17} m^2 / s, g = 9.8 m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	9.7×10^{3} *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	1.0×10^{4} *years*
3	$11\left(\frac{\nu}{ga}\right)$	1.2×10^{4} *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	4.1×10^{4} *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	1.6×10^{4} *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	1.8×10^{4} *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	2.0×10^{4} *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	2.2×10^{4} *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	2.4×10^{4} *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	2.6×10^{4} *years*

Graph showing the plot of Time Scale against the Order of Deformation

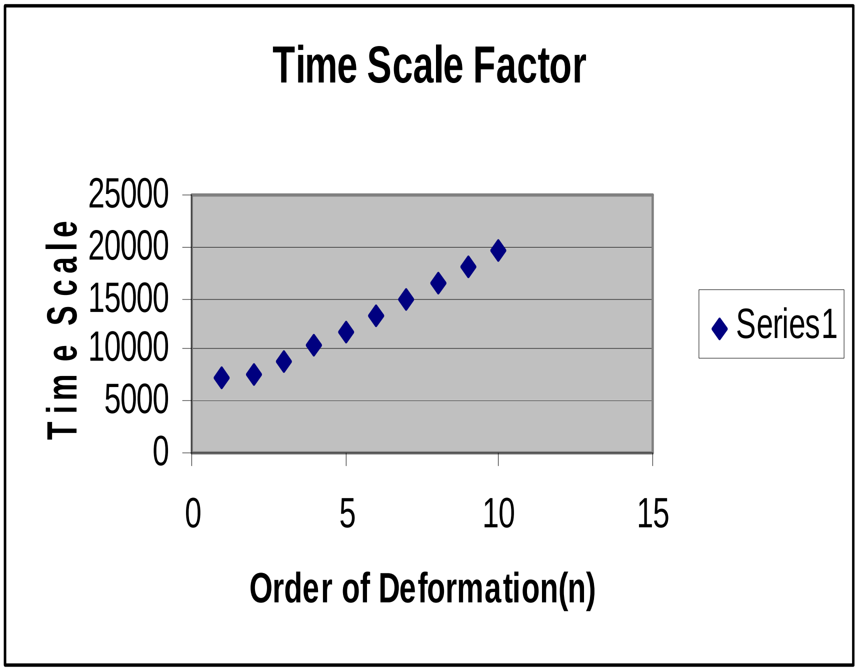


CASE 6.

For $a = 400km, \nu = 10^{17} m^2 / s, g = 9.8 m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	7.3×10^3 *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	7.7×10^3 *years*
3	$11\left(\frac{\nu}{ga}\right)$	8.9×10^3 *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	1.0×10^4 *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	1.2×10^4 *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	1.3×10^4 *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	1.5×10^4 *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	1.7×10^4 *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	1.8×10^4 *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	2.0×10^4 *years*

Graph showing the plot of Time Scale against the Order of Deformation

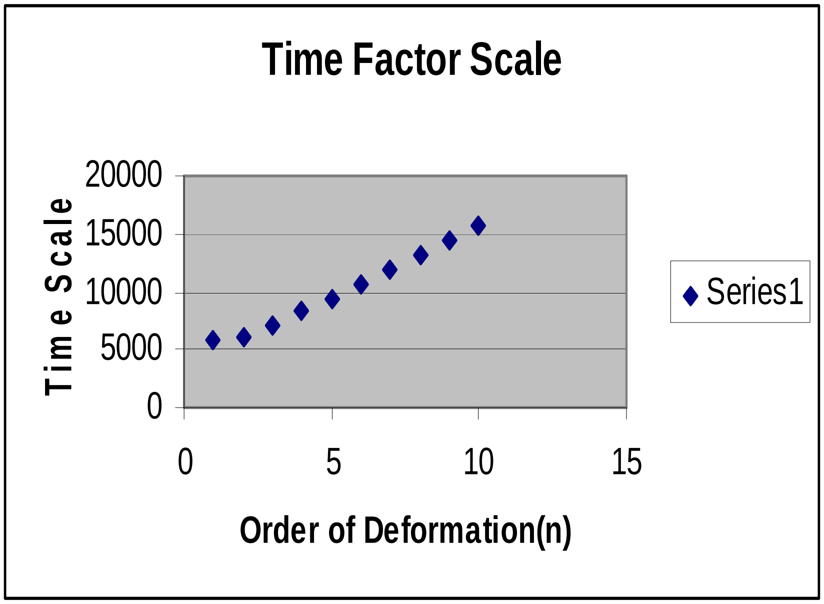


CASE 7.

For $a = 500km, \nu = 10^{17} m^2 / s, g = 9.8m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	5.8×10^3 *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	6.2×10^3 *years*
3	$11\left(\frac{\nu}{ga}\right)$	7.1×10^3 *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	8.3×10^3 *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	9.5×10^3 *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	1.1×10^4 *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	1.2×10^4 *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	1.3×10^4 *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	1.5×10^4 *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	1.6×10^4 *years*

Graph showing the plot of Time Scale against the Order of Deformation

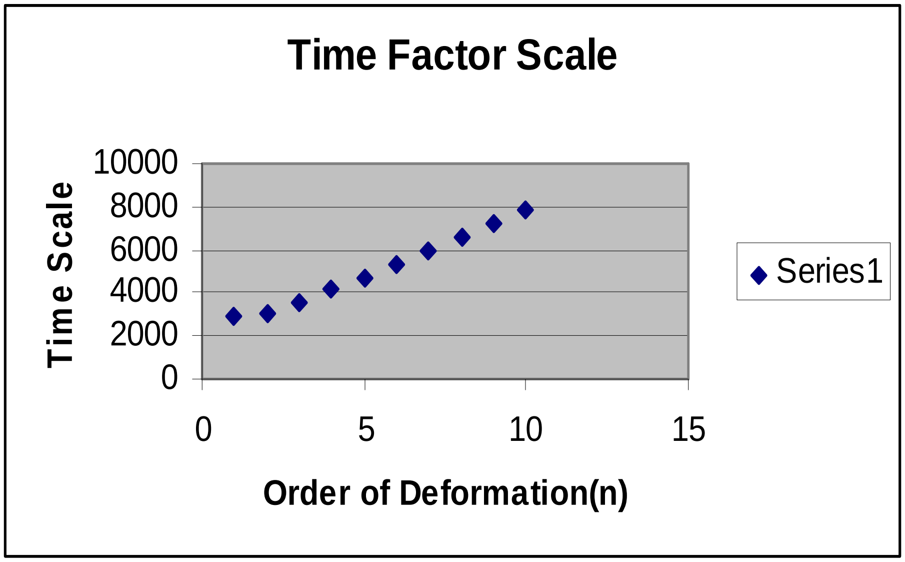


CASE 8.

For $a = 1000km, \nu = 10^{17} m^2 / s, g = 9.8m / s^2$

Order of Deformation(n)	Time Scale $\tau\left(\frac{\nu}{ga}\right)$	Time Scale $\tau(years)$
0	$0\left(\frac{\nu}{ga}\right)$	0 *years*
1	$9\left(\frac{\nu}{ga}\right)$	2.9×10^3 *years*
2	$9.5\left(\frac{\nu}{ga}\right)$	3.1×10^3 *years*
3	$11\left(\frac{\nu}{ga}\right)$	3.6×10^3 *years*
4	$12.75\left(\frac{\nu}{ga}\right)$	4.1×10^3 *years*
5	$14.6\left(\frac{\nu}{ga}\right)$	4.7×10^3 *years*
6	$16.5\left(\frac{\nu}{ga}\right)$	5.3×10^3 *years*
7	$18.43\left(\frac{\nu}{ga}\right)$	6.0×10^3 *years*
8	$20.375\left(\frac{\nu}{ga}\right)$	6.6×10^3 *years*
9	$22.33\left(\frac{\nu}{ga}\right)$	7.2×10^3 *years*
10	$24.3\left(\frac{\nu}{ga}\right)$	7.9×10^3 *years*

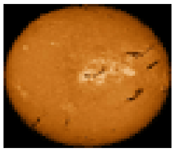
Graph showing the plot of Time Scale against the Order of Deformation



1.1 Checking for Spherical of different planets

We know clearly that objects of radius of order $10^2\,km$ or less will not necessarily be at all spherical

SUN

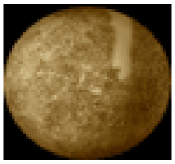


Period: 0.00days   Rotation: 30days

Distance: 1.015au   Diameter: 1392000km

$$TheRadius = \frac{diameter}{2} = \frac{1392000km}{2} = 686000km$$

MERCURY

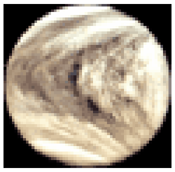


Period: 87.97days   Rotation: 58.65days

Distance: 0.642au   Diameter: 4878km

$$TheRadius = \frac{diameter}{2} = \frac{4878km}{2} = 2439km$$

VENUS

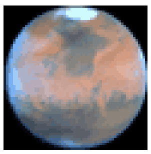


Period: 224.70days   Rotation: 243.01days

Distance: 1.252au   Diameter: 12104km

$$TheRadius = \frac{diameter}{2} = \frac{12104km}{2} = 6052km$$

MARS

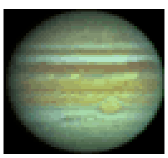


Period: 1.88yrs   Rotation: 24.62hrs

Distance: 2.095au   Diameter: 6787km

$$TheRadius = \frac{diameter}{2} = \frac{6787km}{2} = 3393.5km$$

JUPITER

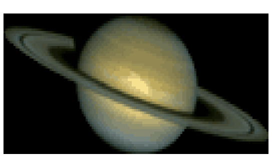


Period: 11.86YRS   Rotation: 9.84hrs

Distance: 4.68au   Diameter: 142980km

$$TheRadius = \frac{diameter}{2} = \frac{142980km}{2} = 71490km$$

SATURN

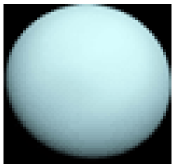


Period: 29.46yrs   Rotation: 10.66hrs

Distance: 9.55au   Diameter: 120540km

$$TheRadius = \frac{diameter}{2} = \frac{120540km}{2} = 60270km$$

URANUS

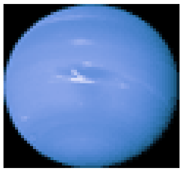


Period: 84.01yrs Rotation: 17.23hrs

Distance: 18.829au Diameter: 51200km

$$TheRadius = \frac{diameter}{2} = \frac{51200km}{2} = 25600km$$

NEPTUNE

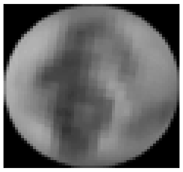


Period: 164.79yrs Rotation: 16.10hrs

Distance: 29.321au Diameter: 49530km

$$TheRadius = \frac{diameter}{2} = \frac{49530km}{2} = 24765km$$

PLUTO



Period: 247.69yrs Rotation: 153.28hrs

Distance: 28.932au Diameter: 2300km

$$TheRadius = \frac{diameter}{2} = \frac{2300km}{2} = 1150km$$

1.2 Calculating different time scale τ for the planetary objects,

$$\tau = \frac{2(n+1)^2+1}{n}\frac{\nu}{ga}$$

When the kinematic viscosity is $10^{20}\,m^2/s$, n = 2 and radius (r) = a

PLANETS	n	$r(km)$	$\nu(m^2/s)$	$g(m/s^2)$	$\tau(years)$
SUN	2	686000	10^{20}	9.8	4.5×10^3
MERCURY	2	2439	10^{20}	9.8	1.3×10^6
VENUS	2	6052	10^{20}	9.8	5.1×10^5
MARS	2	3393.5	10^{20}	9.8	9.1×10^6
JUPITER	2	71490	10^{20}	9.8	4.3×10^4
SATURN	2	60270	10^{20}	9.8	5.1×10^4
URANUS	2	25600	10^{20}	9.8	1.2×10^5
NEPTUNE	2	24765	10^{20}	9.8	1.2×10^5
PLUTO	2	1150	10^{20}	9.8	2.7×10^6

CHAPTER TWO

2. CONCLUSION

The effects of gravity are completely dominant for bodies of radii larger than a few hundred kilometers, which even if they were severely damaged would return closely to spherical form in times of the order $10^3 - 10^6\,years$;nevertheless,bumps and pits of heights typically of order 10km can be a permanent features.

2.1 NOTATIONS

C ·············· Wave (or phase) velocity

D ·············· Diameter

F ·············· Force

M ·············· Mass

$Q(q)$ ·············· Discharge

$R(r)$ ·············· Radius, also the universal gas constant

X, Y, Z ·············· Volume of body force (gravity) along OX, OY, OZ, respectively.

d ·············· Depth (wave theory)

g ·············· Gravity acceleration

n ·············· Element

t, T ·············· Time

u, v, w ·············· Components of the velocity vector along the three coordinate axes OX, OY and OZ respectively.

x, y, z ·············· Coordinates of a point along OX, OY and OZ respectively

μ ·············· Coefficient of viscosity also scale, vertical

ν ·············· Kinematic coefficient of viscosity

ρ ·············· Density

σ ·············· Normal stress

τ ·············· Time scale also time interval or shearing stress

ϕ ·············· Potential function

$$v = -grad\phi$$

$$\left(u = -\frac{\partial \phi}{\partial x}, v = \frac{\partial \phi}{\partial y}, \frac{\partial \phi}{\partial z} \right)$$

$\frac{\partial A}{\partial *}$ ·············· Partial derivative (with respect to *)

ς_n ·············· Surface-harmonic of integral order n

s_n ·············· Surface harmonic

Ω ·············· Gravitational-potential

γ ·············· Gravitational constant

P ·············· Pressure

T ·············· Kinetic energy

V ·············· Potential energy

$\overline{F}$ ·············· Total dissipation