Astronomy 192 Section 001

Homework 4 – Due Wednesday, February 9th

Name __________________KEY___________________________

Student Number (Last 4 digits only!) ____0000_______________

The purpose of this assignment is to improve your understanding of force, mass, weight and acceleration. You will need to use data on the Earth, Moon and Planets given in the Appendices of your book.

Part I. (25 points) Bob is an astronaut. (To qualify for space flight, he has to watch his weight. So he always carries a trusty scale with him!) He has a mass of 70 kg. On his first mission, he is "spacewalking" in orbit at an altitude of 1,000 km above the Earth's surface.

A. Calculate the gravitational force that the Earth exerts on Bob using Newton's law on page 138 of your text. (Don't forget that d is the distance from the center of the Earth to Bob.) Your answer should be expressed in units of 1 Newton = 1 kg m/s^2.

F_g =5.12 x 10^2 Newtons

Use Newton's force law given on page 138 with

M_1 = 70 kgs

M_2 = 5.97 x 10^{24} kgs = mass of the Earth

d = 7,378 kms = 7.378 x 10^6 meters

G = 6.67 x 10^{-11} $m^3/(kg\ s^2)$

B. If this is the only force acting on Bob, calculate his acceleration.

a = F_g / M_1 = 7.31 m/s^2

This is Newton's second law.

C. Now assume that Bob has returned to Earth. As he exits the space shuttle, he jumps in the air off the last step and falls gently to the ground. Repeat Parts A and B above for the brief few moments when Bob is in the air before he touches the ground.

Force on Bob	F_g = 6.85 x 10^2 Newtons
Acceleration of Bob	a =F_g / M_1 = 9.79 m/s^2

These are obtained just as in Parts A and B, but with d = 6,378 kms which is the radius of the Earth. (Note that Bob's acceleration is also calculated on Page 147 of your textbook.)

D. Bob worries that he ate too many doughnuts in space. So he places his trusty scale on the tarmac and steps on it. The Earth is pulling him down with the same force you calculated in Part C. The massive spring inside the scale is holding him up by pushing him upward with a force of contact F_C. If Bob stands still on the scale, his acceleration is zero. What is the value of F_C ? (This is what we call Bob's weight.)

$F_C = 6.85 \times 10^2$ Newtons

By Newton's second law

$$F_C - F_g = M_1 a$$

where the left-hand-side gives the total force on Bob. Since Bob is not accelerating a=0, and so the scale exerts a force equal to the earth's gravitational force.

Part II. (15 points) On his next mission, Bob goes to the Moon. Characteristically, he jumps off the last step of the ladder from the lunar lander before he falls gently to the Moon's surface.

A. Calculate the gravitational force that the Moon exerts on Bob using Newton's law on page 138 of your text. (Don't forget that d is the distance from the center of the Moon to Bob.) Your answer should be expressed in units of Newtons.

$F_g = 1.14 \times 10^2$ Newtons

Use Newton's force law given on page 138 with

$M_1 = 70$ kgs

$M_2 = 7.349 \times 10^{22}$ kgs = mass of the Moon

$d = 1{,}738$ kms $= 1.738 \times 10^6$ meters

$G = 6.67 \times 10^{-11}$ $m^3/(kg\ s^2)$

B. If this is the only force acting on Bob as he falls, calculate his acceleration.

$a = F_g / M_1 = 1.62\ m/s^2$

This result is also obtained (approximately) on Page 147 of your textbook.

C. Now Bob places his scale on the lunar surface. If he steps on the scale now, how much will he weigh?

$F_C = 1.14 \times 10^2$ Newtons

Once again his acceleration is zero, so the scale has to exert a force equal to the gravity force.

Part III. (30 points) Back from the Moon, Bob goes to mission headquarters. He is disturbed by the result of Part C above, and wants to talk to mission experts. He boards the elevator to take him to the mission room on the top floor. While in the elevator, just to check, he places his trusty scale on the floor and stands on it. What does the scale read at each of the following times?

A. While the elevator accelerates upward at a rate of 1 m/s^2.

Again, by Newton's second law

$$F_C - F_g = M_1 a$$

where the left-hand-side gives the total force on Bob. Since Bob is back on Earth, F_g is 685 Newtons, as we found in I. C. Now, however, Bob is accelerating at $a = 1\ m/s^2$, and so the scale must exert a larger force equal to F_g plus $M_1 a$.

$F_C = 7.55 \times 10^2$ Newtons

B. While the elevator then moves upward at constant speed.

Now a=0 again, so

$F_C = 6.85 \times 10^2$ Newtons

C. While the elevator then decelerates at a rate of -1 m/s^2 until it comes to rest on the top floor.

Now Bob is accelerating at a = -1 m/s^2, and so the scale must exert a lesser force equal to $F_g + M_1 a$

$F_C = 6.15 \times 10^2$ Newtons

You've been on elevators. How does the pressure you feel on your feet change as the elevator starts up, or as the elevator comes to rest on the top floor?

D. Mission experts tell Bob not to worry. His MASS hasn't changed in all of his years at NASA. Relieved but somewhat befuddled, he boards the elevator again, hops on his trusty scale, and sets off for the ground floor. Initially, the elevator accelerates downward at a rate of -1 m/s^2. What is his weight now?

$F_C = 6.15 \times 10^2$ Newtons

This is exactly the same as III.C. Note that the direction of motion doesn't matter, it's the direction of the acceleration that matters!

E. While it then moves downward at a constant speed?

$F_C = 6.85 \times 10^2$ Newtons

Same as Part B.

F. Finally, as it accelerates upward at a rate of +2 m/s^2 before coming to rest?

$F_C = 8.25 \times 10^2$ Newtons

So the elevator not only has to oppose gravity, it also has to stop Bob's fall.

Part IV. (10 points) What would happen to the force of contact with the scale if the elevator accelerated downward at a rate of 9.8 m/s^2?

F_C = 0 Newtons

This is basically the same rate of acceleration as Bob in free fall (see I. C). An elevator accelerating downward at this rate is in free fall also. So Bob and the elevator are both falling freely, and there is no contact force between them.

Part V. (20) Many years later, Bob (whose mass is still 70 kgs) is afraid he's losing his memory. He has landed on one of the planet's of the Solar System, but can't remember which one! So he hops aboard his trusty scale and finds that he weighs 259.76 Newtons. Which planet is Bob on?

Use Newton's force law given on page 138 with

M_1 = 70 kgs
M_2 = 6.42 x 10^{23} kgs = mass of Mars
d = 3,397 kms = 3.397 x 10^6 meters
G = 6.67 x 10^{-11} $m^3/(kg\ s^2)$

and you will find F_g = 259.76 Newtons. Bob is on Mars.

All of these things are discussed qualitatively in Section 5.1 of your textbook.

All of these discussions will be important later in the course when we talk about Einstein's theory of General Relativity and the nature of Black Holes.