Exercise Physiology Problem Set #1

Mt Whitney is the highest mountain in the 48 contiguous states. Standing 4,418 **m** (14,494 feet), its east face rises over 10,000’ above the nearby Owens Valley of eastern California. The east face is a favorite target of accomplished rock climbers. Typically they leave from a camp at approximately 11,000’ (about 3353 m) and climb the vertical wall of fractured granite to the summit. The best climbers using the “easiest” route in good weather conditions and can complete this climb in less than 10 hours. They then return to base camp by a well-worn trail used by many hikers and even pack animals.

Suppose that our climber has a mass of 60 kg. Further, assume that she climbs vertically and that air resistance and friction are negligible.

(i) What is the value of the force (in **Newtons**) that she must overcome when climbing?

She is lifting her mass (60 kG) against a constant acceleration due to gravity (9.8 ms^{-2}). Thus:

$F = m * a = 60$ kG * 9.8 $ms^{-2} = 588$ N

(ii) How much work does she do (in **Joules and kJ**) in climbing the vertical distance from base camp to the summit? If **one kcal** ≈ **4.2 kJ**, how much work did she do in Kcal.

She climbs from 3353 to 4418 m. Thus her climb = 1065 m. The force needed to move her body is 588 N (see above). So:

W = E = F * d = 588 N * 1065 m = 626,220 J or 626 kJ

Since 1 Kcal ≈ about 4.2 kJ, then this is the equivalent of 626/4.2 ≈ 150 Kcal

(iii) Does she actually do the amount work than you calculated in (b)? Explain.

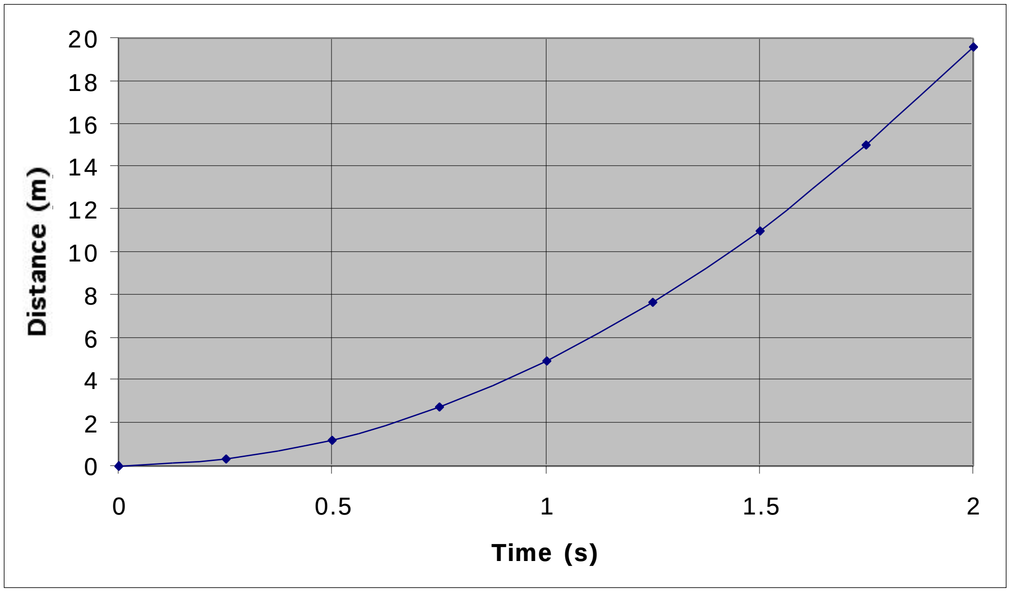
Anyone who has just climbed the face of Mt. Whitney is very tired. They have done far more work than the equivalent of 150 kcal raised through 1065 m. In fact, most of the work in this case is not simply lifting ones body against gravity. Instead, it is all of the movement, wedging, twisting, friction and grabbing needed to hang onto a vertical wall. So, our assumptions have caused a major underestimate of the actual work done in the climb.

(iv) Suppose that she completes the climb in 10 hours. Calculate her average power output (using the same assumptions as in (a) and (b)) in **kJ per hou**r. Then calculate the value in **watts**.

The work she did was 626 kJ in 10 hours which is 62.6 kJ/h. Since there are 3600 s in 1 hour, then her power output is:

(62.6 kJ/h) / 3600 (s/h) = 0.0174 kJ/s (*i.e.,* kW)
= 17.4 watts

There is one mishap in her climb. Late on, she slips and falls for two seconds before being belayed (arrested) by her carefully placed rope. Here is a graph of her fall:



In addition, here is a table of the distances and times in the graph above:.

time (s)	distance (m)
0	0
0.25	0.31
0.5	1.23
0.75	2.76
1	4.90
1.25	7.66
1.5	11.03
1.75	15.01
2	19.60

(e) Calculate her average velocity for each 0.25 of her fall.

Velocity = d / t. Thus, the distance covered each 0.25 s is the difference between the distance at the end (d_2) and start (d_1) of the time interval between time t_2 (end time) and t_1 (start). We usually write this d_2-d_1, as Δd (delta d). We can use similar notation for time. So, our equation becomes:

$V = \Delta d / \Delta t$

For the interval from zero to 0.25 seconds, she falls from her starting point 0.31m. Thus, her <u>average</u> velocity during this time is:

0.31 m / 0.25 s = 1.23 m/s

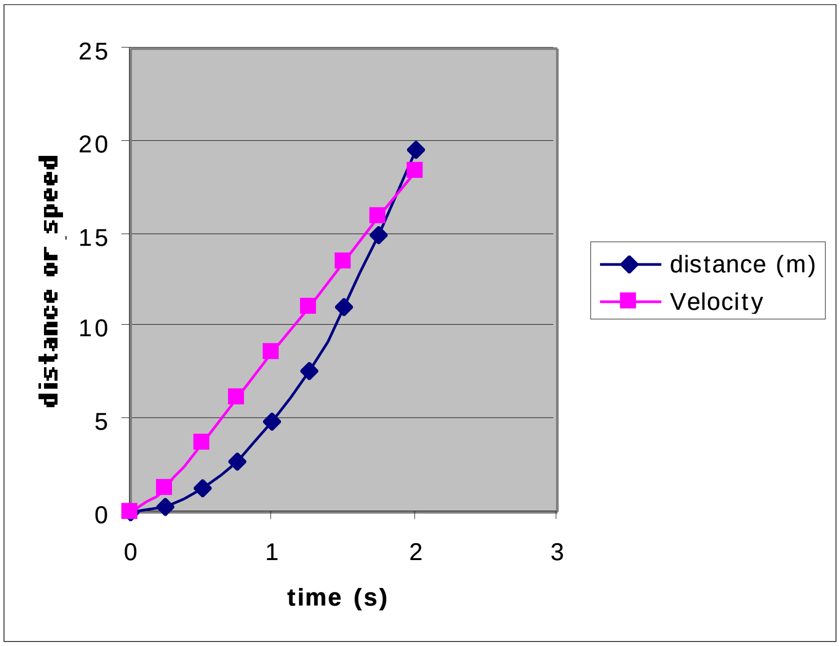
During the time from 0.25 to 0.5 s, she falls from 0.31 to 1.23 – an additional 0.92 m. in this 0.25 s. interval. Thus her average velocity is:

0.91/0.25 = 3.68 m/s

Here are the values and answers for the rest of the fall

time (s)	distance (m)	delta time	delta distance	Velocity
0	0	0.25	0	0
0.25	0.31	0.25	0.31	1.225
0.5	1.23	0.25	0.92	3.675
0.75	2.76	0.25	1.53	6.125
1	4.90	0.25	2.14	8.575
1.25	7.66	0.25	2.76	11.025
1.5	11.03	0.25	3.37	13.475
1.75	15.01	0.25	3.98	15.925
2	19.60	0.25	4.59	18.375

and a graph (which you didn't have to make) of her distance and velocity over time:



(f) Calculate her average acceleration for the 0.5 to 0.75, and the 1.5 to 1.75 s. intervals? Is this what you would have expected? Briefly explain.

Acceleration is the rate of change in velocity. Thus, using the notation above, the average acceleration in some specific interval of time is:

$a = \Delta v / \Delta t$

for the 0.25 s interval between 0.5 and 0.75 s, her velocity increased from 3.68 to 6.12 m/s (see table above), an increase in velocity of 2.44 m/s. Thus, her acceleration was:

$a = 2.44\ m/s / 0.25 s = 9.8\ m/s^2$

A similar calculation for 1.5 to 1.75 s. gives:

$a = (15.92 - 13.48\ (m/s)) / 0.25\ s = (2.44\ m/s)/0.25\ s$

= 9.8 m/s^2
The acceleration is constant, as must be the case since she is being accelerated by gravity.

(g) When the rope arrests her it stretches (permanently) approximately 1 m and stops her in 0.25 s. Climbing ropes are supposed to do this. What is the <u>average</u> force she feels (through her seat harness) during the 0.25 s when she her fall is being arrested?

In this case she slows from her speed at 2s (= 18.4 m/s – see above) to 0 m/s in 0.25 s.

Thus, her average acceleration is:

a = (0 - 18.4m/s) / 0.25 s = -18.4 / 0.25 = -73.6 m/s^2 (the negative sign means that she is de-accelerating).

She still weighs 60 kG and thus,

F = 60 kg * 73.6 m/s = 4416 N
(incidentally, this is 7.5 X the force of gravity!).

The reason that you use a seat harness and not one around, for instance, your chest or arms should be obvious – the force is applied from the bottom throughout the torso. The result is a compressive force applied from your butt upwards – it is less likely to dislocate bones and tear muscles!

Two additional things to think about that have relevance to topics we will soon cover:

(i) If the rope did not stretch and therefore stopped her instantaneously, would the force she experienced have been greater? Why must climbing ropes be designed to stretch?

The force would be far greater since the climbers speed

would decrease in the same amount but in a shorter time.

Climbing ropes must stretch enough so that breaking a fall does not produce high accelerations that break bones or cause other injuries. On the other hand, they must not act like bungee cords and stretch a long distance -- for obvious reasons. Incidentally, a rope that experienced this type of a fall would have to be retired – it does not return to the same shape. The same principles apply to other sports equipment – for example bicycle helmets.

(ii) Go back to your answer in question (b). This represents the work or energy change involved in moving her body a certain distance. However, it is not the amount of energy she needed to use to make the climb. That is because she is not 100% efficient in turning the energy she "burns" during the climb into actual movement. Efficiency is defined as:

$$\text{Efficiency}(\%) = \frac{\text{"Useful Work" (WorkOutput)}}{\text{Work needed to accomplish the "Useful Work"}} * 100$$

If our climber is 10% efficient, how many **Kca**l did she use in the climb?

Here, the "useful work" was the energy stored in her body during the climb. We have seen earlier that it was 150 kcal. If she was 10% efficient, then if we re-arrange the equation above we can find her work input:

Work input = work output/(efficiency/100)

Using the values given:

= 150 kcal/ (10/100) = 150 / 0.1 = 1500 kcal.

Once again, this number is an absurd underestimate of

the amount of energy she needed to use to perform the climb for the same reasons outlined earlier. On the other hand, it does illustrate that much of the energy used in exercise does not end up as useful work – instead, we will see that it is wasted as heat. More about this later in the course.