HOMEWORK #02

Course: MCEN 5228 – Modeling of Human Movement

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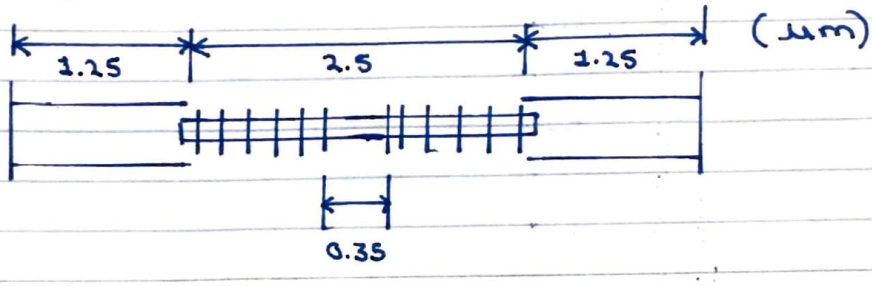
Problem 1) :→

We are given the sarcomere specimen of a T-rex.

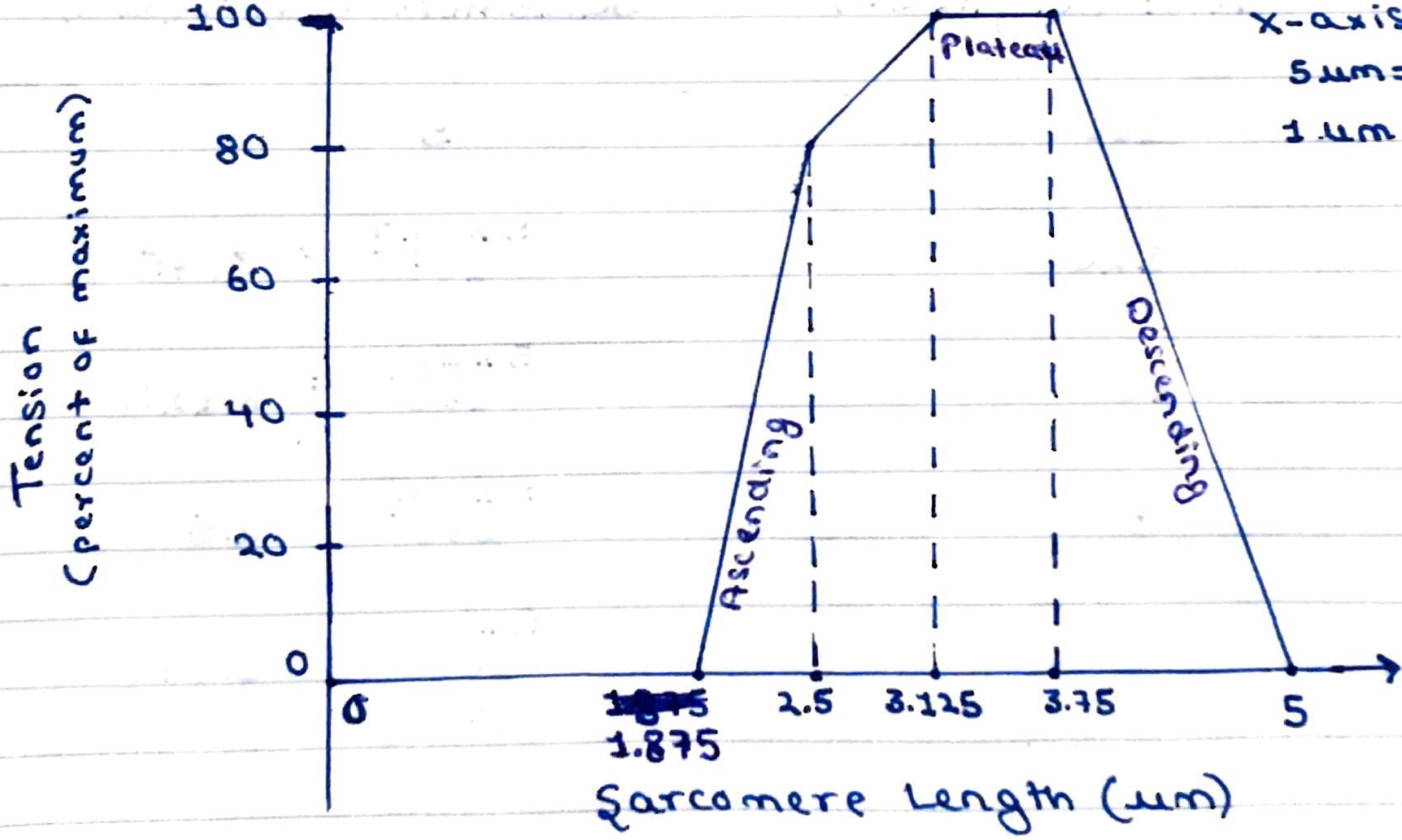


We are required to determine the active portion of the force-length curve for the T-rex sarcomere. We can take the help of force-Length relationship of a sarcomere with Relative force on y-axis and Rest length (%) on x-axis

Rest Length (%)	Sarcomere Length (μm)
160	5
120	$\frac{5\times120}{160} = 3.75$
100	$\frac{5\times100}{160} = 3.125$
80	$\frac{5\times80}{160} = 2.5$
60	$\frac{5\times60}{160} = 1.875$

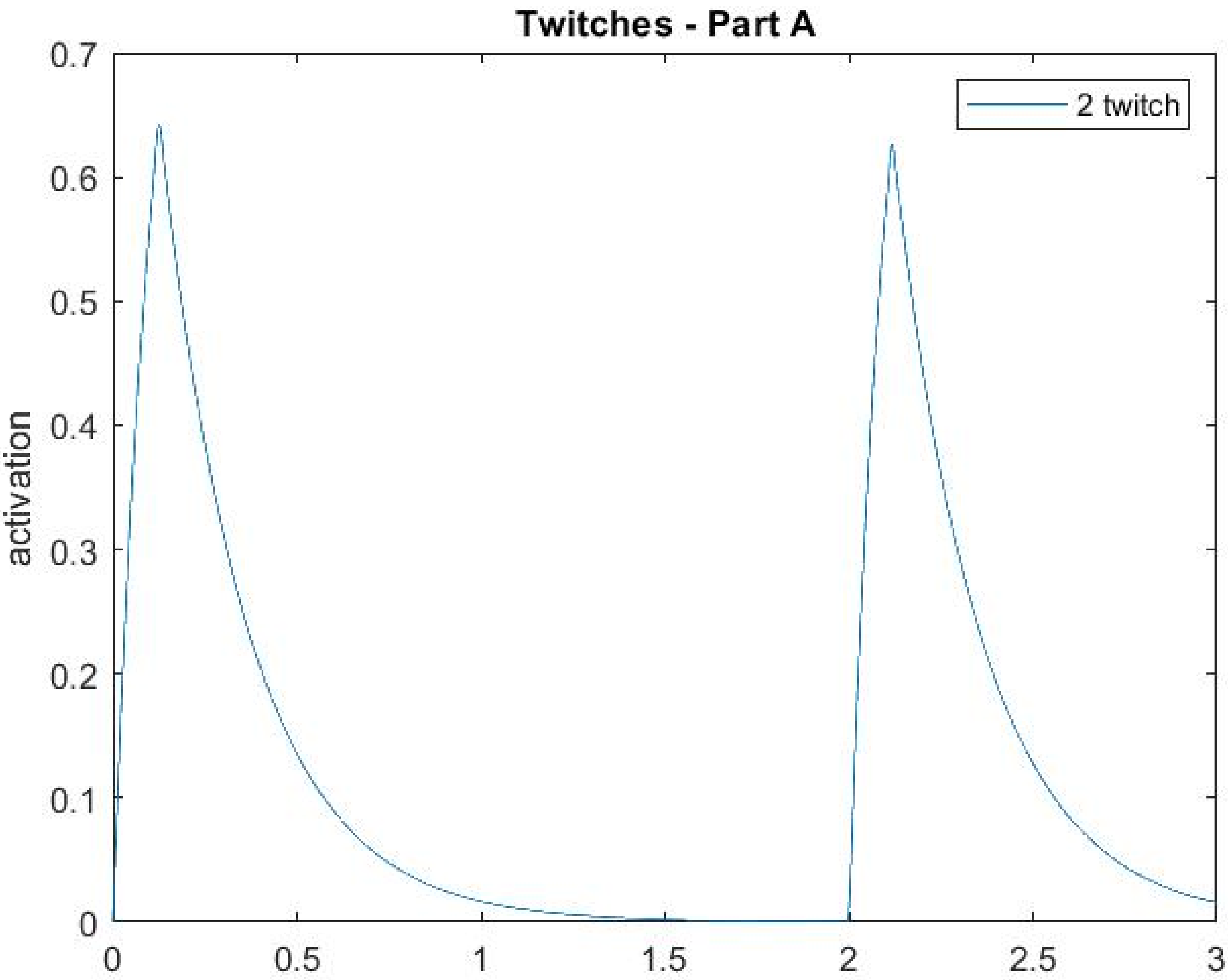
→

Scales:-
x-axis :
5 µm = 10 cm
1 µm = 2 cm

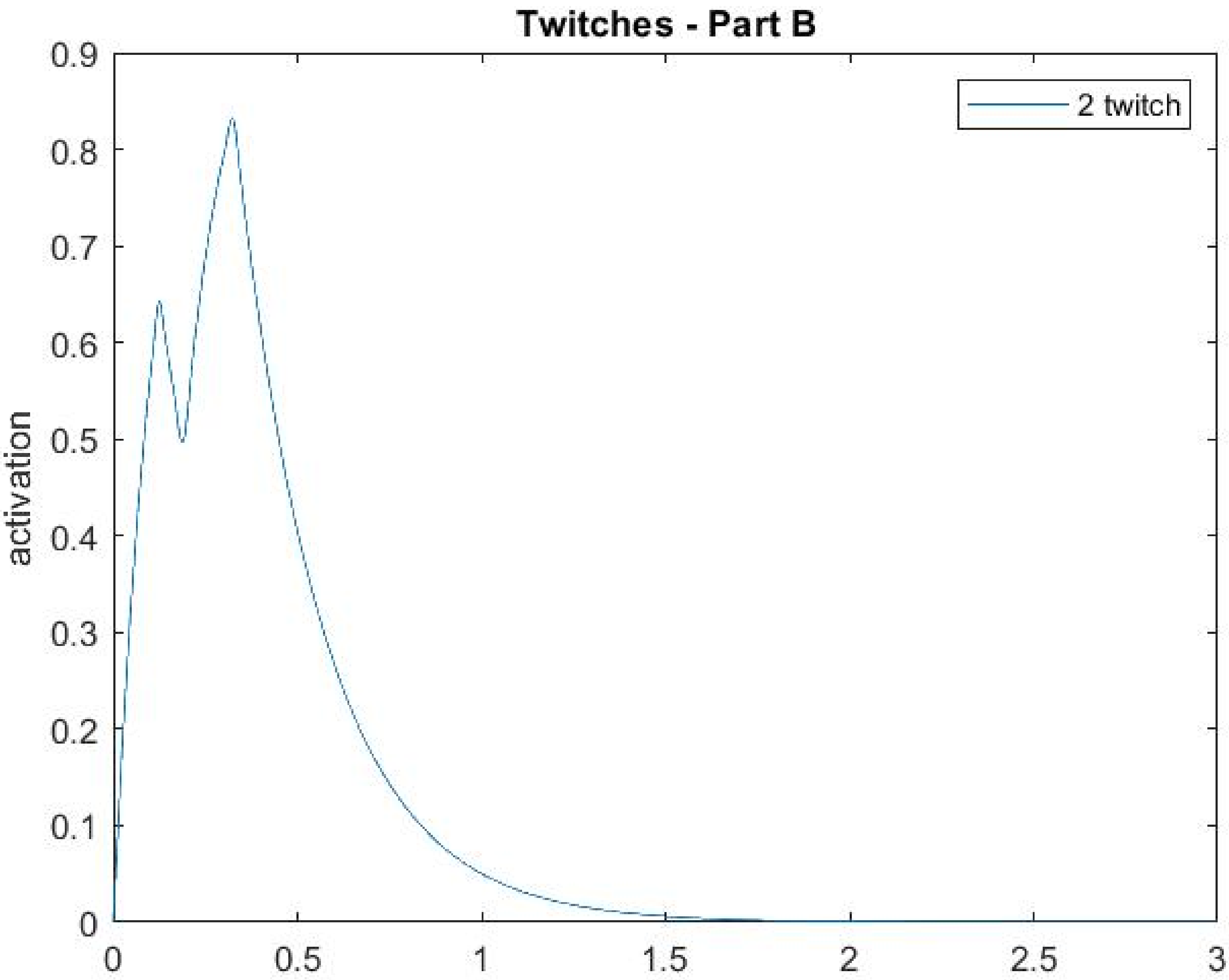


Problem 2) :-

The peak activation is higher for part b then part a. This can be understood with the help of muscle activation and rate encoding because of neural stimulation. The muscles are activated when the calcium ions release from the sarcoplasmic reticulum and bind to the troponin protein complex. This causes the tropomyosin to change its shape and the binding sites are revealed. Also, at the neuro-muscular junction, rapid progression of action potential is allowed by the muscle structure. Therefore, if second impulse comes along before the first one has relaxed, they gets added and thereby we can get more force with multiple impulses. This is the case which happens with part b, because before the first impulse is relaxed we get the second one and thus we get more force and higher peak activation.



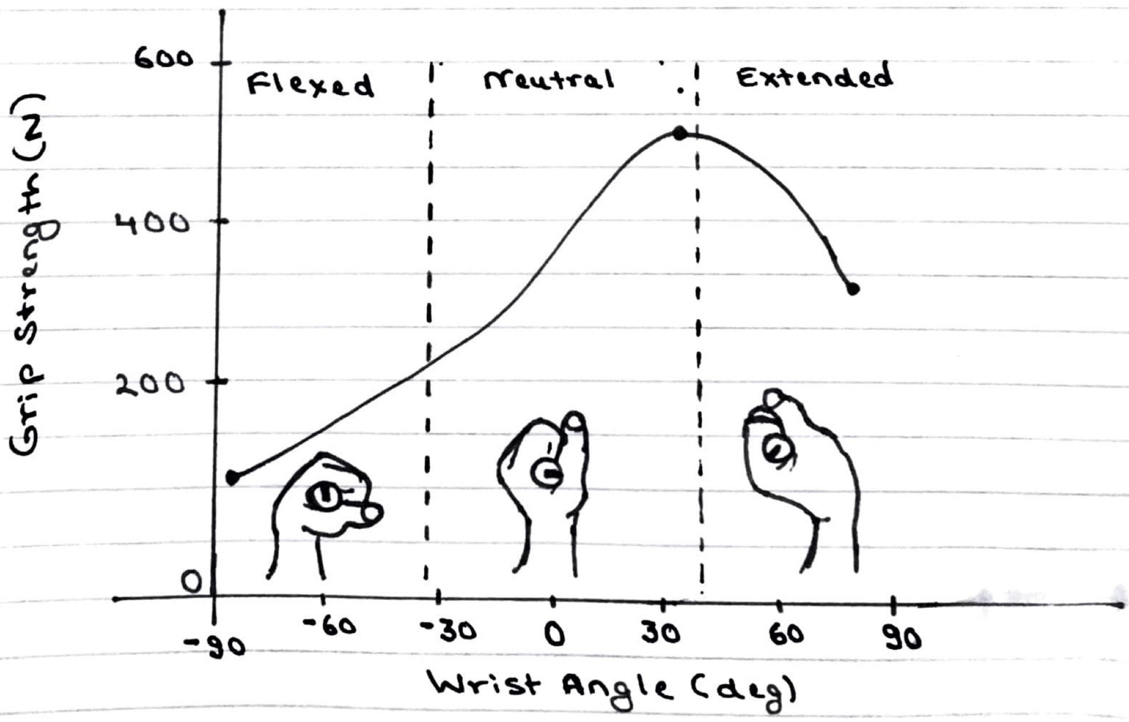
Twitches - Part A
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
activation
0
0.5
1
1.5
2
2.5
3
2 twitch


Twitches - Part B
activation
2 twitch
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
0.5
1
1.5
2
2.5
3

Problem 3) :- ~~The wrist area~~

Grip strength depends on the wrist position. Optimal grip force is produced with the wrist in 35° extension and 5° ulnar deviation. As the wrist is flexed, grip force is reduced. Wrist flexion between 15-30 degrees is the strongest position because this movement has less radial and ulnar deviation. Lengthening of musculotendinous units and loss of movement in radio-carpal and inter-carpal joints can be main reason for weak grip force.

Grip force is reduced as wrist flexion increases due to the shortened position of the finger flexors and the passive extension force created by the finger extensor muscles. When the wrist is fully flexed, the flexor muscles become too short and they are unable to create enough tension.



Problem 4) :→ a)

Given:

Spring stiffness, $k = 200\ N/mm$

Stride frequency $= 1.3$ strides/sec

Change in COM per step $= 10\ cm = \Delta L$

Course duration $= 5$ minutes

To find: Energy stored in mass-spring model over the course of 5 minutes.

The spring in the stance phase is compressed by ΔL length, then

Elastic potential energy, $U = \frac{1}{2} k (\Delta L)^2$

$$\Rightarrow U = 1/2 \times \left(\frac{200}{10^{-3}}\right) \frac{N}{m} \times (10 \times 10^{-2} m)^2$$

$$\Rightarrow U = 1000\ J \text{ per step}$$

We know that, Stride frequency $= 1.3$ strides/sec

$\therefore$ No. of strides in 5 min $= 1.3 \frac{\text{strides}}{\text{sec}} \times 5 \times 60$ sec

$= 390$ strides

Stride length is the distance covered when you take two steps, one with each foot.

$\therefore$ 1 stride $= 2$ steps

Therefore, there will be $390 \times 2 = 780$ steps in 390 strides over 5 minutes.

Total energy stored $= 780$ steps $\times 1000$ J/step

$= 780 \times 1000\ J = \underline{780\ kJ}$ //

b) :-

We are given that if there was no spring, muscles performed the same displacements. We are required to find how much positive mechanical work would perform in this scenario. The mechanical work would be perform by gravitational potential energy.

Gravitational Potential Energy (GPE) = $Mg(\Delta L)$
where, ΔL = Change in COM per step or distance travelled by the COM

$\therefore$ Mechanical work done by muscles to lift the COM = GPE = $Mg\Delta L$ = W

Let us assume an adult of mass 70 kg.

$$\therefore \quad W = 70 \times 9.8 \times 0.1$$
$$W = 68.6 \text{ J per step}$$

From the part a, we know that over the course of 5 minutes, we have 780 steps performed. ~~by the~~

$$\therefore \quad W = 68.6 \times 780$$
$$W = \underline{\underline{58508 \text{ J}}} \ //$$

c) Given that, muscle efficiency $= 25\%$.
We are required to find metabolic energy for the same displacements as given in part a.

$$\text{Muscle efficiency} = \frac{\text{Mechanical Work}}{\text{Metabolic Energy}} \times 100$$

$$\Rightarrow \quad \frac{25}{100} = \frac{\text{Mechanical work}}{\text{Metabolic Energy}}$$

From part b, we found out that, $W = 53508\ J$

$$\therefore \quad \frac{1}{4} = \frac{53508}{\text{metabolic energy}}$$

$$\Rightarrow \quad \text{Metabolic energy} = 214032\ J$$

$\therefore$ Metabolic energy required to do same displacements is $214032\ J$, or $214\ kJ$.

d):- Tendons are connective tissues that attach muscle to the bones. They possess high tensile strength and function to transmit the mechanical force that help in the movements of the structures. While running or in other physical tasks, elastic tendons helps to minimize the energetic cost of muscular contraction. Tendons are known to be the strongest connective tissues that can withstand all the mechanical forces gravitating on the body. Tendons also help to regulate the speed of the movement while running. Tendons are highly compliant, have low hysteris and stores elastic energy which helps in running or other physical activities.

The largest tendon present in the body, Achilles, stores energy and enables the calf muscles to work more slowly so ~~has~~ as to deliver more power while running. Tendons spreads the load between the muscles over time which helps to protect the muscles against injury. when doing strenous tasks like running and braking for a bit. This is how an elastic tendon helps in carrying out physical activity like running or any other tasks.

Problem 5):-

a) Work done when a muscle shortens a distance x under a load F, can be written as,

$$\boxed{W = Fx}$$

b) Total amount of heat liberated or Shortening heat is given by, $\phi = ax$

$\therefore$ Total energy expended by a muscle shortening a distance x under a constant load F, will be given by,

$$\cancel{TE = W + \phi}$$

$$\Rightarrow \cancel{TE = Fx + ax}$$

$$\Rightarrow \boxed{\cancel{TE = x(F+a)}}$$ ~~where a is a constant~~

$$TE = A + W + \phi$$

$$TE = A + Fx + ax$$

$$\boxed{TE = A + x(F+a)}$$

- Heat $\rightarrow (A + ax)$
- Work $\rightarrow (Fx)$

where, A is Activation Heat and a is constant

c) Rate of energy expended by a muscle shortening a distance x under a constant load F, can be given as,

$$TE = (F+a)x + A$$

Lets, say Extra energy liberation $= (F+a)x$

$\therefore$ Rate of extra energy liberation

$$\boxed{E = (F+a)\,dx/dt \quad // \\ E = (F+a)v}$$

d) Given that, rate of energy expended is linearly proportional to the negative of the load F, and the rate of energy expended reduced to zero when $F = F_0$ (F_0 is a constant)

Rate of energy released is directly proportional to the difference between max load (F_0) and the actual load F, i.e $E \propto (F_0 - F)$

$$\Rightarrow \boxed{(F + a)\, v = b\,(F_0 - F)}$$

where b is proportionality constant

e) From the above equation,

$$\Rightarrow (F + a)\, v = b(F_0 - F)$$
$$\Rightarrow Fv + av = bF_0 - bF$$
$$\Rightarrow Fv + bF = bF_0 - av$$
$$\Rightarrow F(v + b) = bF_0 - av$$
$$\Rightarrow \boxed{F(v) = \frac{bF_0 - av}{(v + b)}}$$

Multiplying and dividing by F_0, we get,

$$\Rightarrow F(v) = \frac{\left[b - (a/F_0)v\right] F_0}{(v + b)}$$

Given that, $a = 14.35$ gm.wt $= 14.35 \times 9.8 \times 10^{-3}$ N

($\because$ 1 gm wt $= 9.8 \times 10^{-3}$ N)

$b = 1.03$ cm/s $= 0.0103$ m/s

$a/F_0 = 0.22 \quad \Rightarrow F_0 = 0.639$ N

$$\Rightarrow \boxed{F(v) = \frac{\left[0.0103 - 0.22v\right] 0.639}{(v + 0.0103)}} \text{ N}$$

$$\Rightarrow \boxed{F(v) = \frac{(1.03 - 0.22v) \times 65.23}{(v + 1.03)}} \text{ gm wt}$$

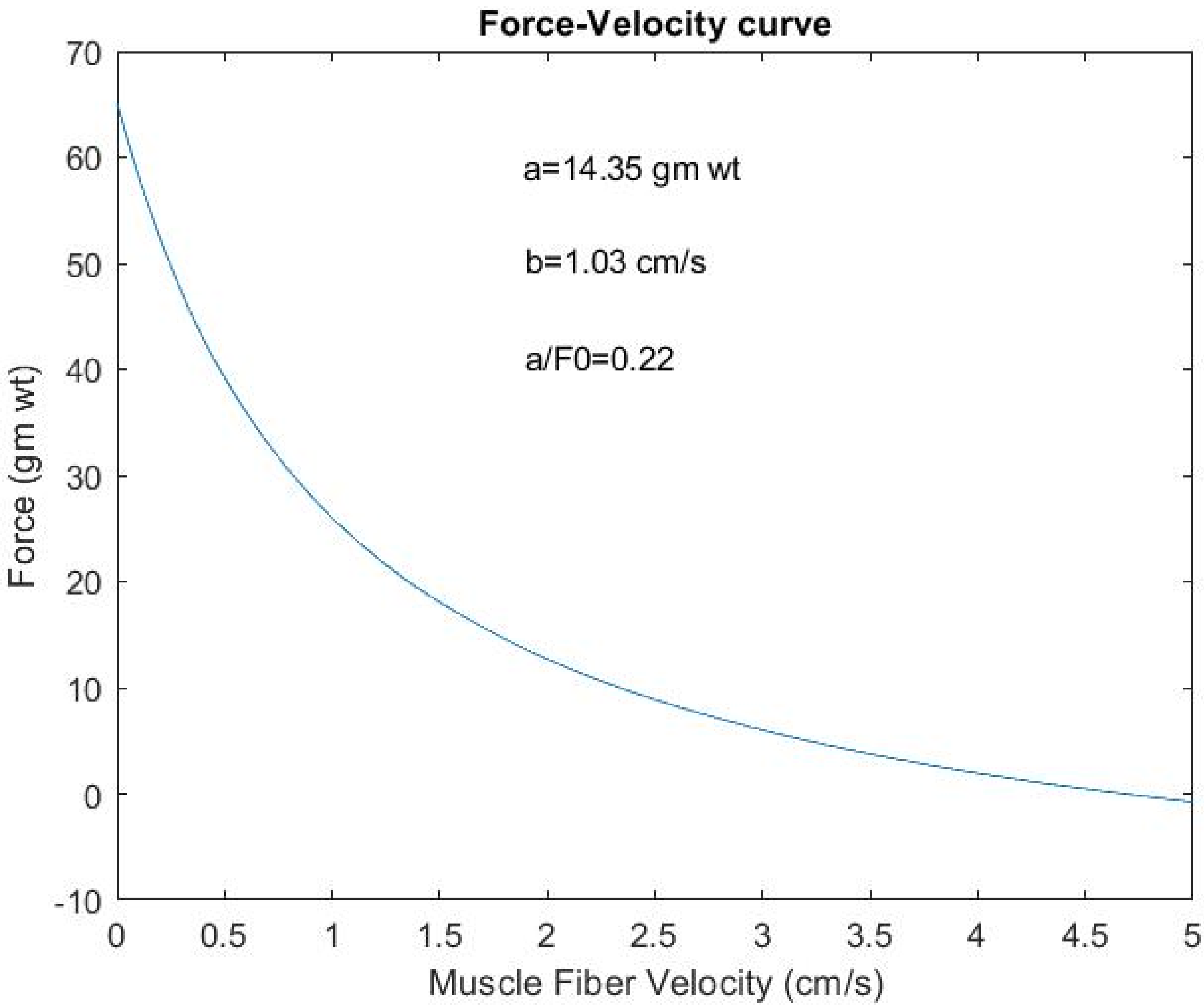
f) Power = Force x velocity

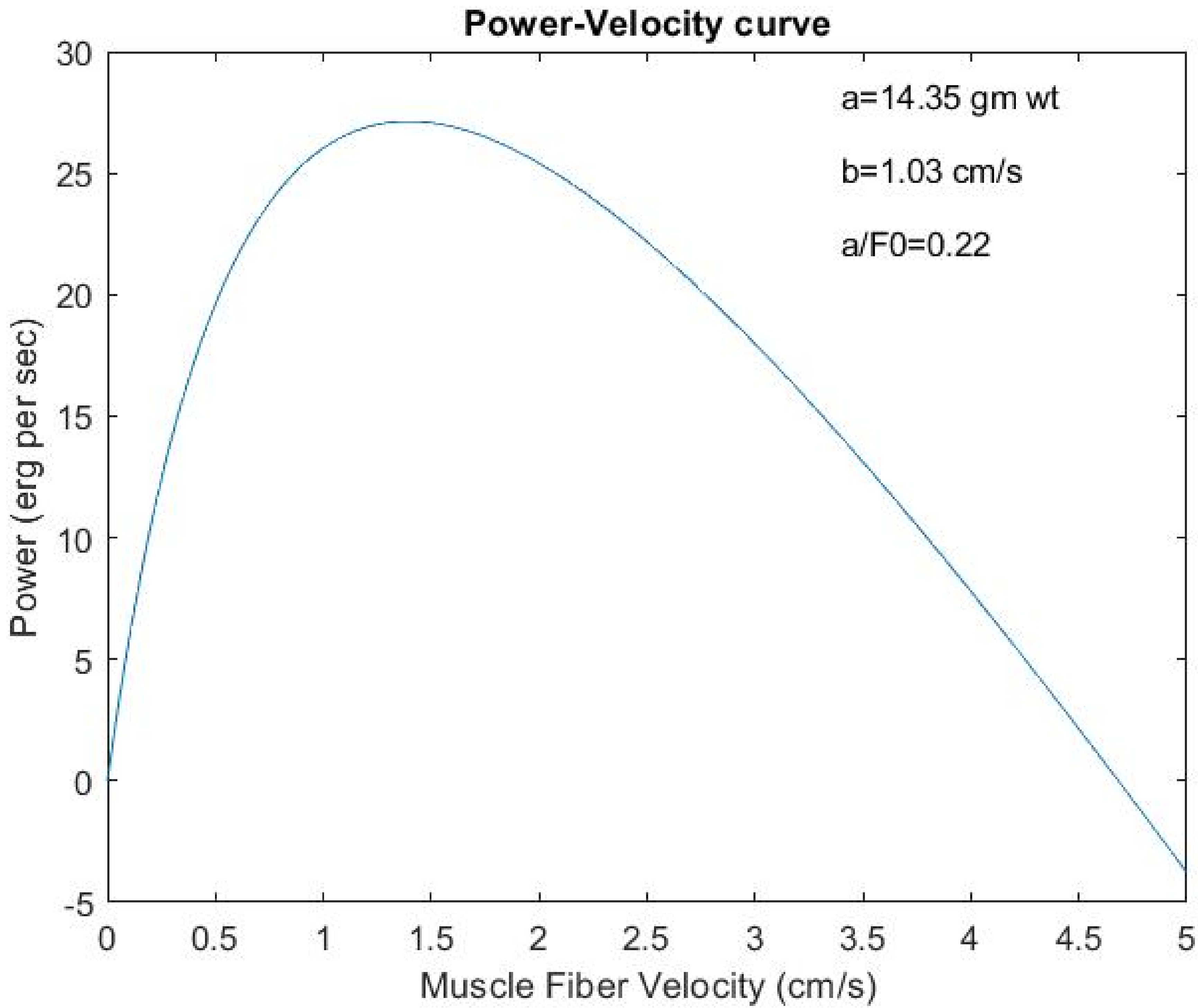
$$\Rightarrow P = F(v) \times v$$

$$\Rightarrow \boxed{P = \frac{(1.03v - 0.22v^2) \times 65.23}{(v + 1.03)}} \text{ erg/sec}$$

g) Maximum power is generated at 1/3rd of maximum shortening velocity.

∴ According to the plot, the peak power of 27.1337 erg/sec occurs at 1.3955 cm/sec.


Force-Velocity curve
a=14.35 gm wt
b=1.03 cm/s
a/F0=0.22
Force (gm wt)
Muscle Fiber Velocity (cm/s)
70
60
50
40
30
20
10
0
-10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Power-Velocity curve
a=14.35 gm wt
b=1.03 cm/s
a/F0=0.22
Power (erg per sec)
Muscle Fiber Velocity (cm/s)
30
25
20
15
10
5
0
-5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5