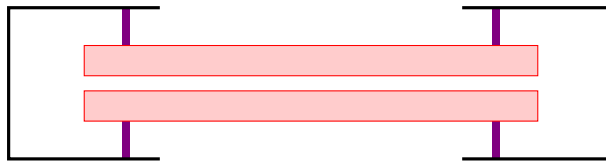


Muscle and Myosin

The structure of a muscle is shown below. The red protein in the middle is called **myosin**, and the purple objects myosin to the external ends are myosin motor proteins. Each fiber has multiple motors associated with it, as we show in the figure: the number of motors per fiber is about 10^3 . Each myosin is about 6 nm thick, as is typical for a protein. The motors are fixed to the myosin, but can walk along the black proteins, and in particular pull the ends closer together. This corresponds to tensing of the muscle, and generates forces. The cell uses energy, in the form of ATP dephosphorylation, to push these motor proteins in small, discrete steps – this is the origin of the forces, as we'll now explore.



- (a) Each time the myosin motor steps, it moves about 10 nm. Each ATP dephosphorylation costs about 10^{-19} J. Estimate the force scale that this motor can generate.¹
- (b) What do you think is the scale of the forces that a typical muscle can exert?²
- (c) Using the previous two parts, if all of the myosin fibers act in unison to generate one big force, about how many myosin fibers are there in a typical muscle?
- (d) Use part (c) to estimate the cross sectional area, and therefore the thickness, of a muscle, and compare to what you know about your own body. Is the answer reasonable?
- (e) The myosin motors expend enough energy to move at about 10^{-5} m/s. How much power does a single myosin fiber expend? How many ATP molecules per second does this correspond to?
- (f) How much power does the entire muscle expend? How many ATP molecules per second is this? Comment on the result – is your answer reasonable?

If your answer to part (f) seems a bit low, remember that some muscles in your body are larger, and that many of them can act in unison to help your body expend energy rapidly!

¹Think about how force relates to energy.

²To answer this question, think about lifting up weights. What is easy to lift and what is heavy?