P8.57 When a ***Click Beetle* is upside down on its back, it jumps upward by suddenly arching its back, transferring Energy stored in muscle to Mechanical Energy. This launching mechanism produces an audible click, giving the Beetle its name. Videotape of a certain click-beetle jump shows that a Beetle of mass $m = 4.0 \times 10^{-6}$ kg moved directly upward by 0.77 mm during the launch and then to a maximum height of h=0.30 m. During the launch, what are the average magnitudes of (a) the external force on the Beetle's back from the floor, and (b) the acceleration of the Beetle in terms of g?

The Beetle arches his back and flexes, jackknifing off the floor by exerting a Force on the Floor. The Floor exerts an equal & opposite force on the Beetle which is responsible for accelerating the Beetle (Gravity acts on the Beetle also) up to the speed he leaves the floor at. The Beetle gains both Kinetic Energy & Gravitational Potential Energy, but it was not transferred by the Force of the Floor acting on the Beetle because the Force of the Floor did not do any Work on the Beetle - the point of application of the Force of the Floor on the Beetle, the Beetle's back, does not move while the Force acts. (Other similar examples are a Person jumping off the ground, climbing stirs, walking, pushing of the wall while on Ice skates (see Text section on External Forces and Internal Energy Transfers.) (NOTE: Beetle's CoM moves while in contact with the Floor.)

In the Click Beetle: Food/Chemical/Electromagnetic Internal Potential Energy is converted into "Spring Potential Energy" in the muscles of the Beetle - the Beetles "Spring" becomes compressed. When the "Spring" releases the Beetle jackknifes off the ground.

Consider application of Work-Energy Theorem to the System consisting of the Beetle alone.
Work-Energy Theorem.: $W_{ext} = \Delta E_{sys} = \Delta E_{mech} + \Delta E_{thermal} + \Delta E_{internal}$

Choose: Initial = when Beetle starts his Flex while his velocity is 0 & height $y_i=0$
Final = when Beetle is at the Top of his Trajectory and $y_f = h$ & $v_f = 0$.

There are two External Forces that act on the Beetle: Gravity & $F_{Beetle_Floor} = F_f$.
Gravity does external Work on the Beetle: $W_{gravity} = -mgh$.
The Force of the Floor on the Beetle does: $W_{floor} \equiv 0$.

$W_{ext} = -mgh = \Delta E_{sys} = (\Delta E_{mech}=0) + \Delta E_{thermal} + \Delta E_{internal}$
$= -(4.0 \times 10^{-6}\ kg)(9.80\ m/s^2)(0.30\ m) = 1.2 \times 10^{-5}$ Joules
NOTE: Human Bodies and Animal Bodies are relatively inefficient, the increase in Thermal Energy will be considerable greater than mgh. The decrease in stored Chemical Potential Energy derived from Food equals mgh plus the Thermal Energy generated.
$\Delta E_{internal} = -mgh - \Delta E_{thermal} < 0 \quad (\Delta E_{thermal} > 0)$

Consider application of Work-Energy Theorem to the System of "Beetle + Earth".
Work-Energy Theorem.: $W_{ext} = \Delta E_{sys} = \Delta E_{mech} + \Delta E_{thermal} + \Delta E_{internal}$

Choose: Initial = when Beetle is at the Top of his Trajectory and $y_i = h$ & $v_i = 0$.
Final = when Beetle is at $y_f = d = 0.77$ mm above the Ground where $v_f = v_{Launch}$

$W_{ext} = 0 = \Delta E_{sys} = \Delta E_{mech} + [\Delta E_{thermal} = 0] + [\Delta E_{internal} = 0]$
$0 = \Delta E_{mech} = \Delta K + \Delta U = (\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2) + (mgy_f - mgy_i) = (\frac{1}{2}mv_f^2 - 0) + (mgd - mgh)$
$\frac{1}{2}mv_f^2 = mg(h-d)$
$v_f = v_{Launch} = \sqrt{[2g(h-d)]} = \sqrt{[2(9.80)(0.30)]} = 2.4$ m/s

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We assume The Beetle has constant acceleration during the Jackknifing which acts over a distance = d: $v_i = 0$ & $v_f = 2.4$ m/s => $v_f^2 = v_i^2 + 2a_y(y_f - y_i)$ where $y_f=d$ & $y_i=0$
$a = a_y = (v_f^2 - v_i^2)/[2(y_f - y_i)] = (2.4^2 - 0^2)/[2(d=0.00077)] = 3{,}700\ m/s^2 =$
$3{,}700\ m/s^2[1g/9.80 m/s^2] = 380$ gs **<----(a) This is a Huge Acceleration that Humans could never withstand, but little critters can due to ...**
We assume The Beetle has constant Force acting on it producing the constant acceleration.
$\mathbf{F}_{net} = m_{Beetle}\mathbf{a} = [4.0 \times 10^{-6}\ kg][3{,}700\ m/s^2]$; take Positive Vectors as UP ...
$F_{net} = F_f - mg = ma$ **the Very Small Force due to Beetle's Small Mass**
$F_f = m(a+g) = [4.0 \times 10^{-6}\ kg][3{,}700\ m/s^2 + 9.80\ m/s^2] = 0.015$ Newtons**<----(b)**