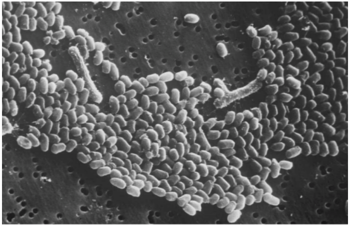
What are These?



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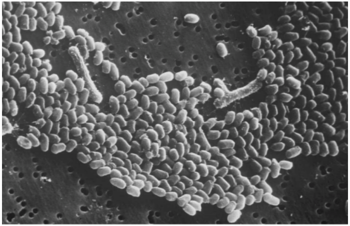

Anthrax spores

1. Until the 20th century, anthrax killed hundreds of thousands of people and animals each year.

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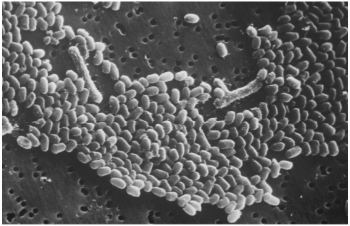

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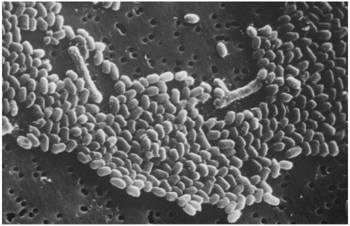

Anthrax spores

1. Until the 20th century, anthrax killed hundreds of thousands of people and animals each year.
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3. A long-standing fear is a biological attack using an agent like anthrax or smallpox.
4. The natural spread of the disease and its indiscriminate nature can amplify the impact.

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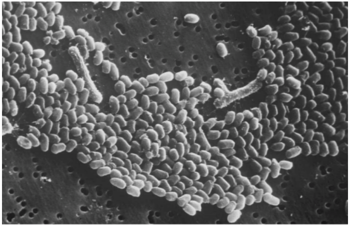

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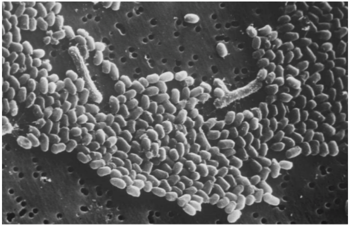
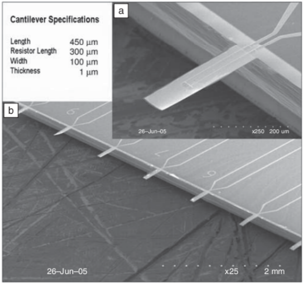
5. Some weaponized forms could cause mass casualties.
6. Defense against such an attack is focused on identification and mitigation.

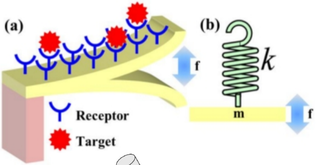
What are These?

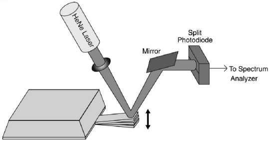


Anthrax spores

1. The attack will not be obvious; it may take hours or days to know.
2. Current biological diagnostics are very effective, but they're slow.
3. Fast response time is essential to avoid overwhelming the health-care system $\Rightarrow$ **rapid response is vital**.







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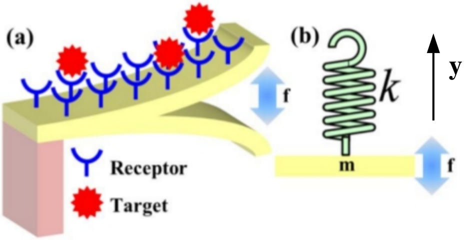
---

4. Nanosized oscillators - cantilevers can be coated with antibodies to bind to spores of specific diseases.
5. As the spores bind, the oscillations of the device change.
6. The change is measured by deflection of a laser beam shining on the cantilever.

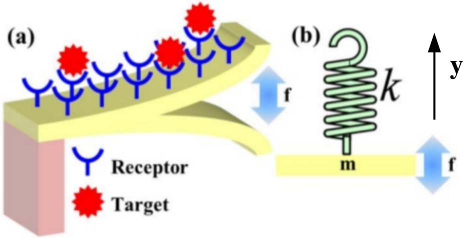
A Nanosized Biosensor - 1

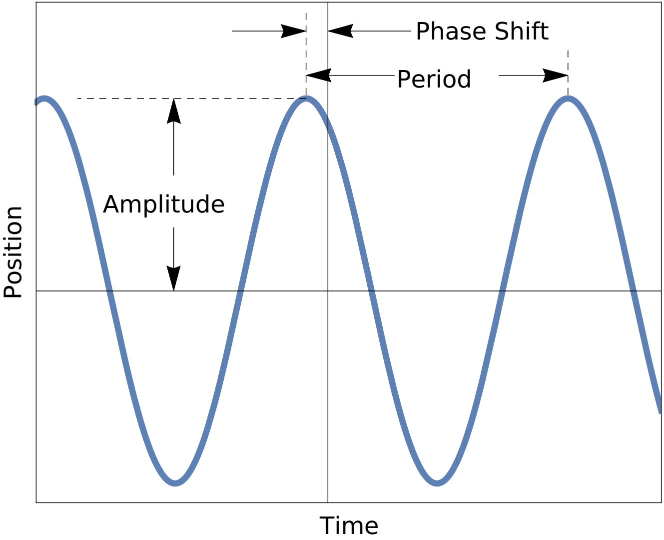
You're a program manager for DARPA and you're evaluating a proposal to use a nano-sized cantilever to detect the presence of anthrax spores quickly and accurately. The device would be used by domestic first responders and warfighters in the field. To test the validity of the proposal consider the following problem. Suppose $n_b = 300$ anthrax spores each with mass $m_b = 10^{-15}\ kg$ are uniformly distributed along the cantilever beam. What is the change $\Delta\omega$ in the natural angular frequency of the cantilever? We can detect frequency changes of $\approx 170\ kHz$. Is this change detectable? WILL IT WORK?



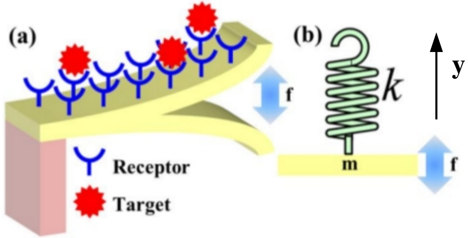
$$L_c = 100\ \mu m$$
$$m_c = 1.49 \times 10^{-12}\ kg$$
$$k_0 = 370\ kg/s^2$$
$$\gamma = 0.139\ s^{-1}$$

The figure shows the idea behind the biosensor. Antibodies (blue receptors) that will bind to anthrax (red targets) uniformly coat a nano-sized cantilever. The cantilever has length $L = 100\ \mu m$ and mass $m_c = 1.49 \times 10^{-12}\ kg = 1.49\ ng$. The restoring force of the beam can be described with an effective spring constant $k_0 = 370\ kg/s^2$. Treating the system as a 'simple' harmonic oscillator, what is the equation for the displacement y of the cantilever from equilibrium? What is the natural angular frequency ω_0 of the cantilever with no adhered anthrax?




Phase Shift
Period
Amplitude
Position
Time

Left alone, the oscillations of the cantilever eventually damp out. Now treat the cantilever as a not-so-simple harmonic oscillator. Before it is exposed to anthrax the system is calibrated by 'plucking' it so at $t = 0$, $y_0 = 9\ \mu m$, and $v_0 = 0$. The amplitude drops to one-half its initial value in $t_{1/2} = 5.0\ s$. What is the drag force? What does Newton's Second Law look like here with friction or damping? What is the damping factor γ?



$L_c = 100\ \mu m$
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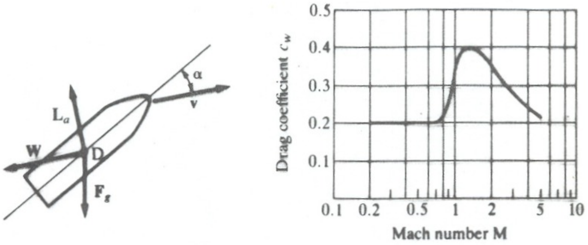
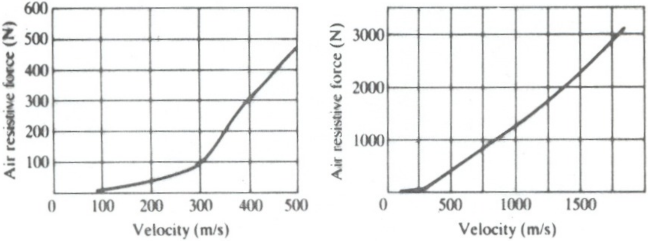
Aerodynamic Drag Forces - 1

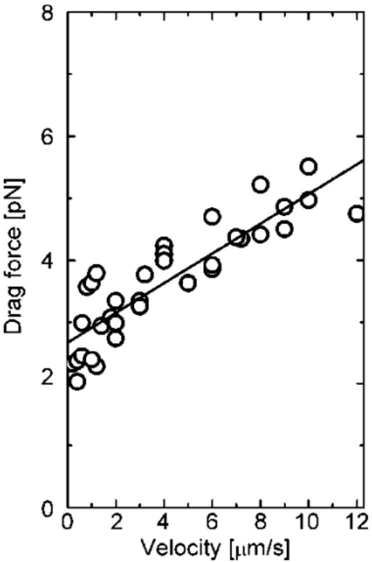
13

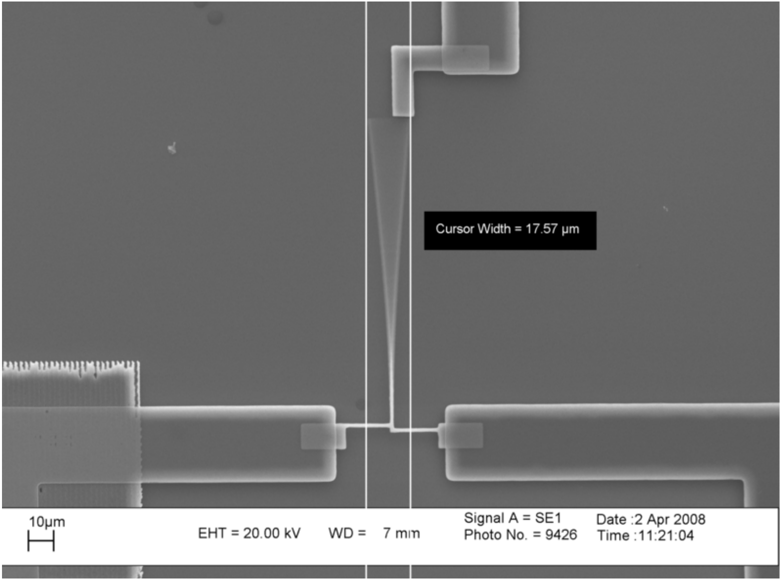


(a) (b)

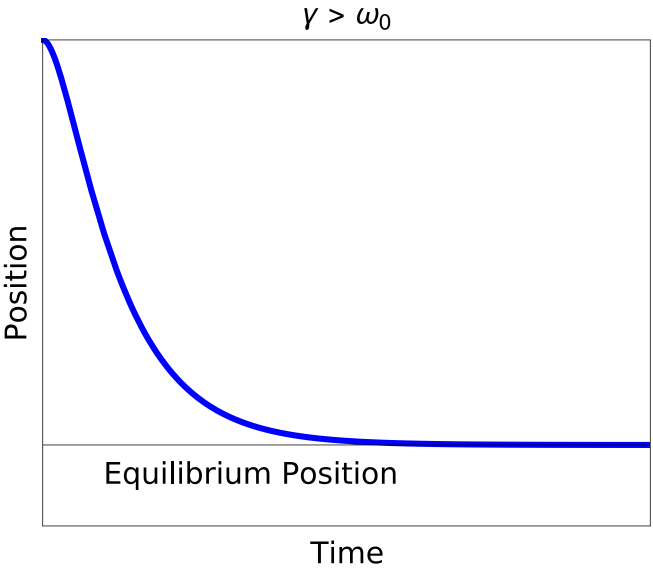


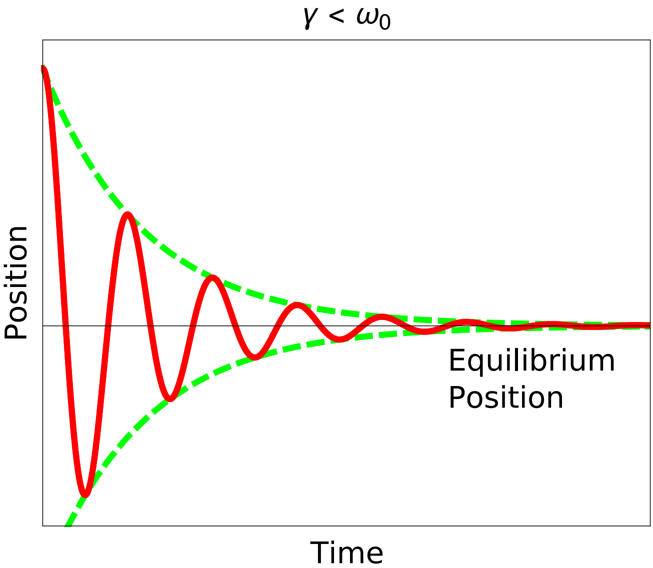
Measurement of drag force versus speed for a partially submerged cantilever dragged through a water-glycol mixture by an atomic force microscope (Mechler *et al. App Phy Lett*, 85, no. 17, 3881 (2004). Offset is likely due to meniscus forces where the cantilever enters the liquid.




Cursor Width = 17.57 µm
10µm
EHT = 20.00 kV
WD = 7 mm
Signal A = SE1
Photo No. = 9426
Date :2 Apr 2008
Time :11:21:04

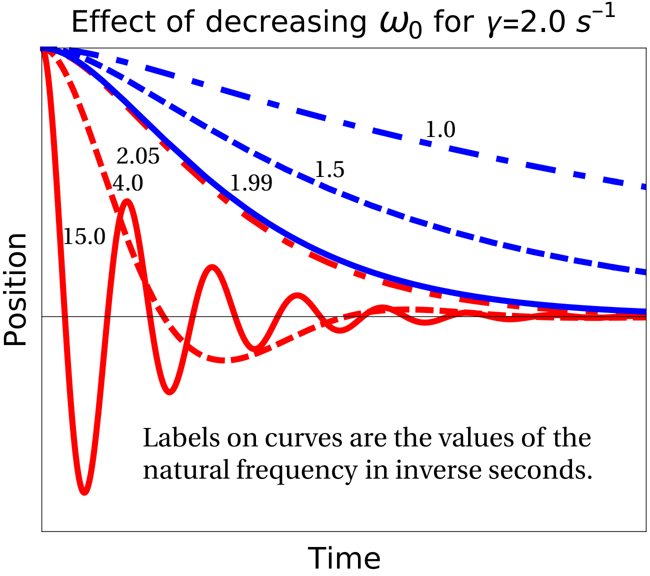
The $\gamma > \omega_0$ Result



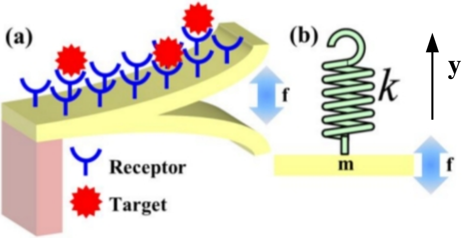


γ < ω0
Position
Equilibrium
Position
Time

Decreasing ω_0 for fixed γ



Now assume an added mass of anthrax $\Delta m = n_b m_b$ is uniformly distributed along the length of the beam where n_b is the number of anthrax bacteria and m_b is the mass of a single anthrax spore. What is the change $\Delta\omega$ in the natural angular frequency in terms of ω_0 and $\Delta m/m_c$? Assume $\Delta m/m_c << 1$ and get your result in a form linear in $\Delta m/m_c$.



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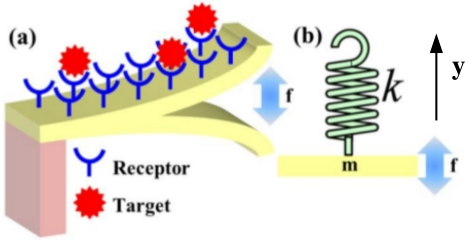

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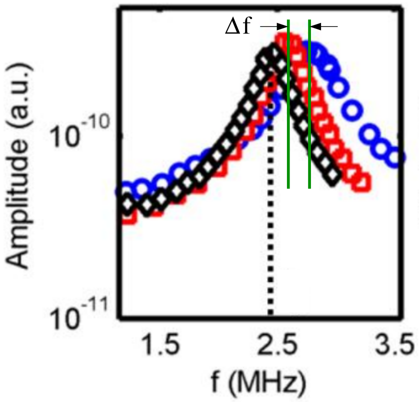
$k_0 = 370\ kg/s^2$
$\gamma = 0.139\ s^{-1}$

Cantilever configuration:

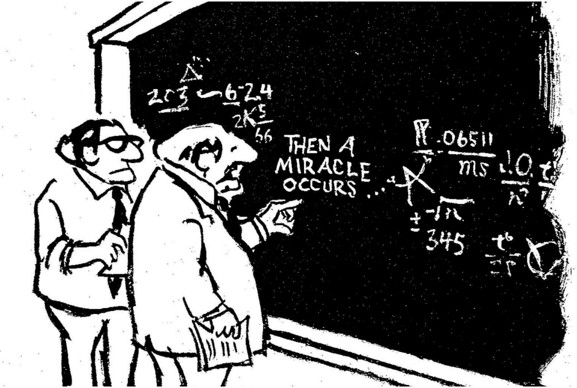
Black diamonds - no receptors.
Red squares - with receptors.
Blue circles - with targets.



Emerging Ideas in Nanocantilever based Biological Sensors, Jain and Alam, Purdue University

Object	Terminal Velocity (m/s)	b (kg/s)
Antibody	3.7×10^{-3}	4×10^{-13}
Parachutist	5	5×10^{-3}
Basketball	20	4
Ping-Pong Ball	9	3×10^{2}
Raindrop	7	5×10^{4}

MAGIC!



I think you should be more explicit here in step two.