EXAM 2 is next week

Time: 8:00-9:30 pm Wed Mar 7
Place: Elliott Hall
Material: lectures 1-15, HW 1-15, Recitations 1-8, Labs 1-8
focus will be on second half of material (not on Exam 1)
Problems: multiple choice, 10 questions (70 points)
write-up part, hand graded (30 points)
Equation sheet: provided with exam
Practice exam + equation sheet: will be posted at the end of this week

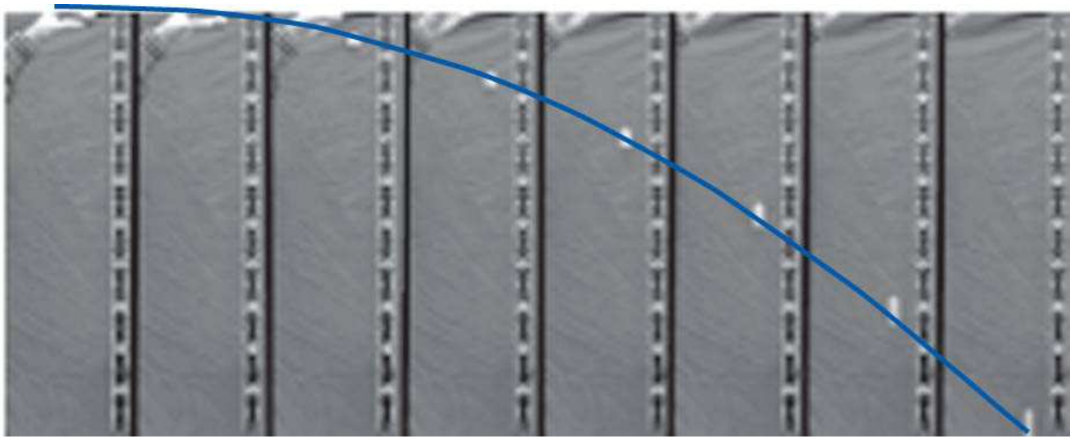
Note: **no lecture on Thursday March 8 !**

Today’s Lecture

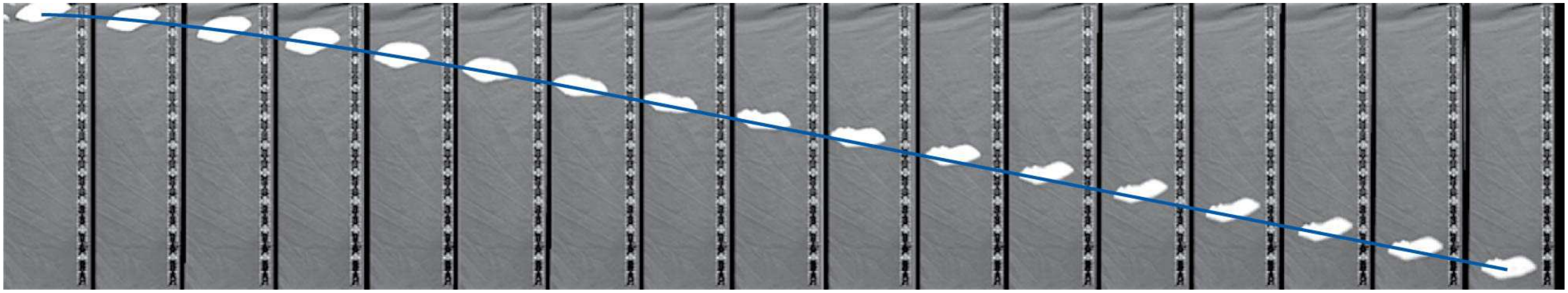
- Friction and Energy Dissipation
- Driven Oscillations and Resonance

Air Resistance

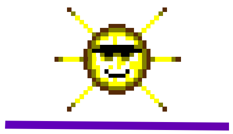
A <u>small metal ball</u> will fall as if gravity is the only force, F=mg.

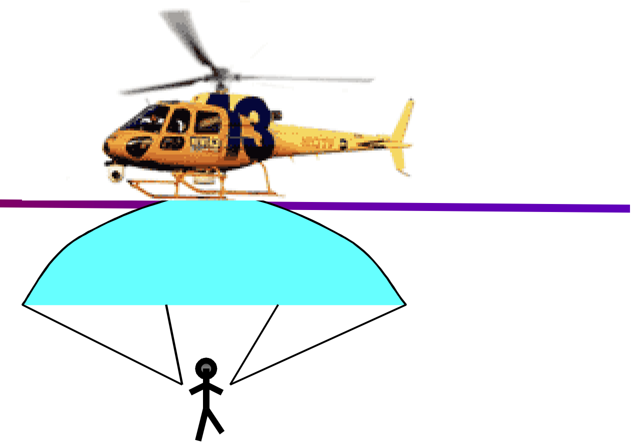


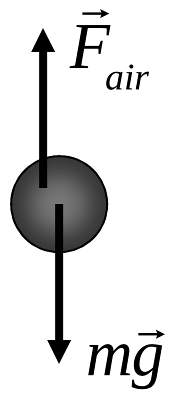
A falling <u>coffee filter</u> does not obey F=mg. Instead it reaches a nearly constant terminal velocity:



Terminal speed







$$\frac{d\vec{p}}{dt} = \vec{0}$$

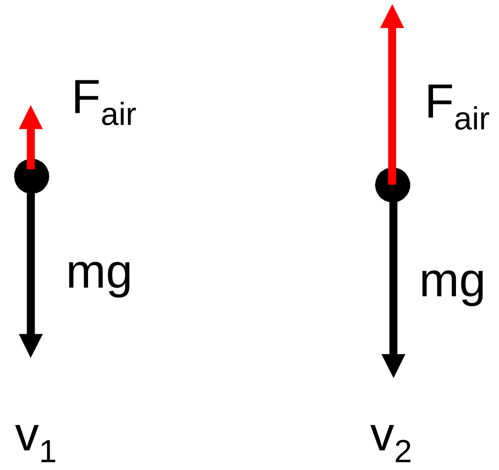
$$\vec{v} = \overrightarrow{const}$$

terminal speed

Approximate Air-Drag Formula

Observations about air resistance:

1. F_{air} is proportional to speed.
2. Increases with area.
3. Depends on density of air.
4. Depends on object's shape (not mass)
5. Opposes direction of motion.



The force due to air resistance can be approximated as:

$$\vec{F}_{air} \approx -\frac{1}{2} C \rho A v^2 \hat{v}$$

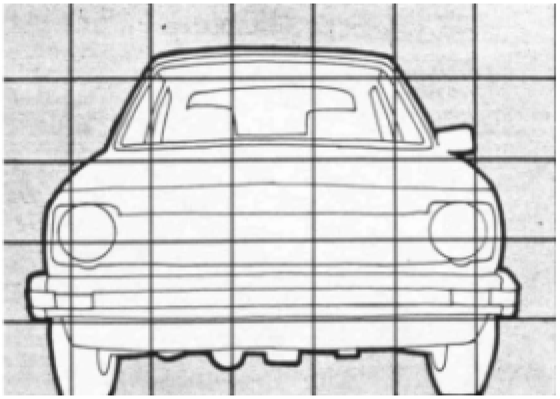
ρ = density of air

A = area of object

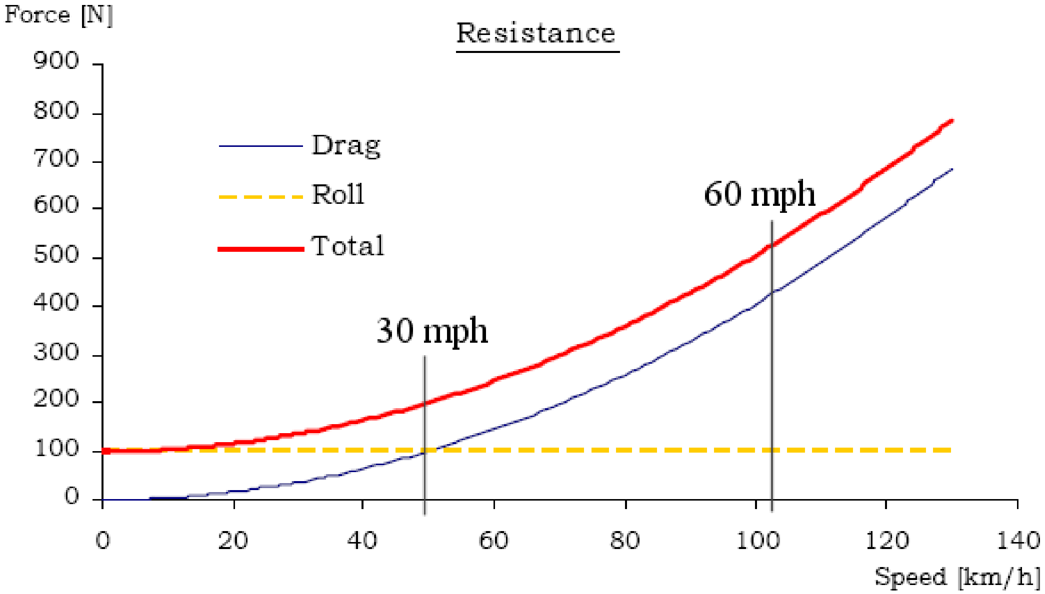
v = speed of object

C = shape-dependent parameter

Application: Fuel Efficiency of a Car



$$\vec{F}_{air} \approx -\frac{1}{2} C \rho A v^2 \hat{v}$$



http://www.atmosphere.mpg.de/enid/Information_ss/Velocity___air_drag_507.html

Daihatsu UFE III: C = 0.16

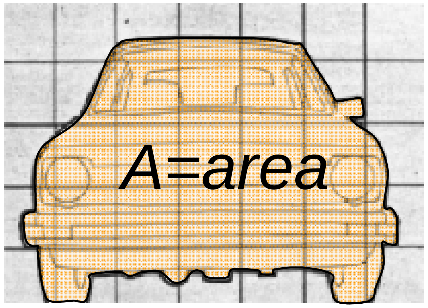
Toyota Prius: C = 0.26

Toyota Tacoma: C = 0.44

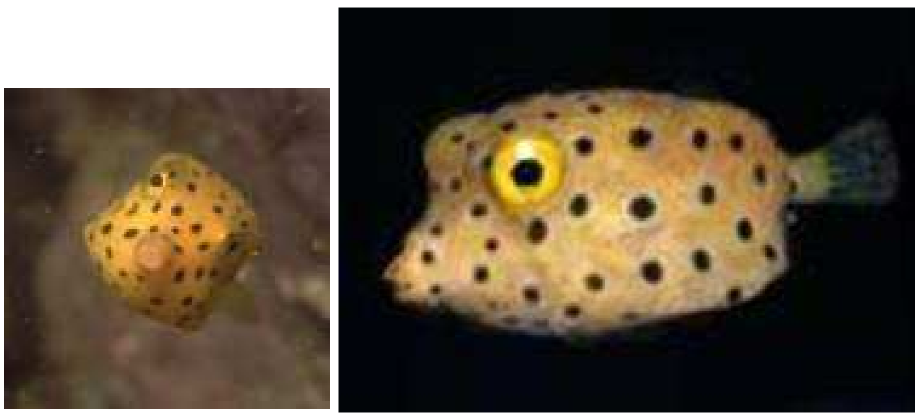
$$F_{air} \approx \tfrac{1}{2} C \rho A v^2,$$

where $0.3 \le C \le 1.0$

Air resistance example: a car



Car	*C (drag)*
Sports	*0.27 – 0.31 – 0.38*
Performance	*0.32 – 0.34 – 0.38*
60's Muscle	*0.38 – 0.44 – 0.50*
Sedan	*0.34 – 0.39 – 0.50*
Motorcycle	*0.50 – 0.90 – 1.00*
Truck	*0.60 – 0.90 – 1.00*
Trailer	*0.60 – 0.77 – 1.20*



Box-fish
C = 0.06

Mercedes concept car
C = 0.19

But wait, there's more to Air Drag!

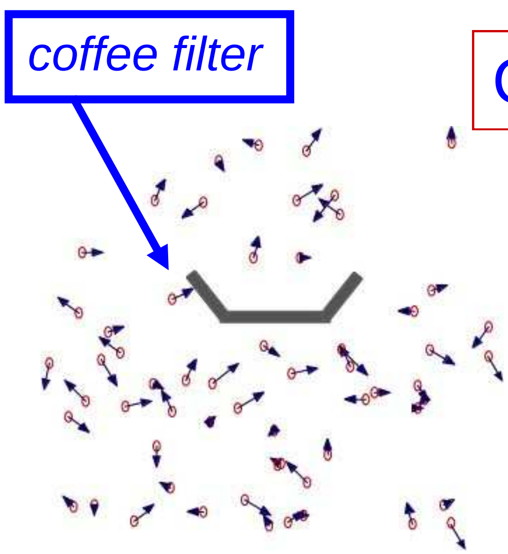
Collisions on the bottom of the falling object impart more impulse than collisions on the top of the falling object.

+

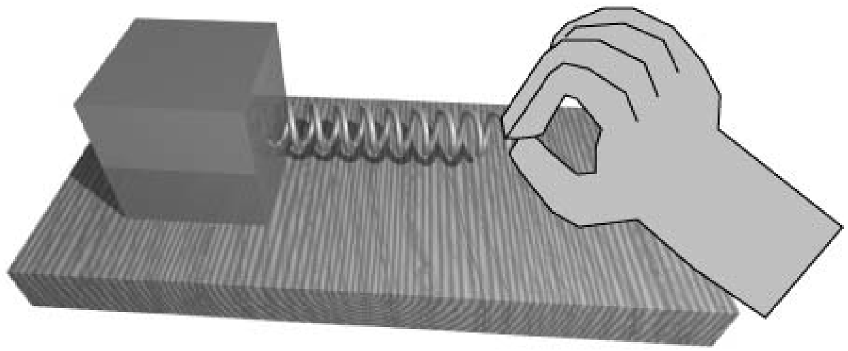
Macroscopic "wind"-like motion of surrounding air

=

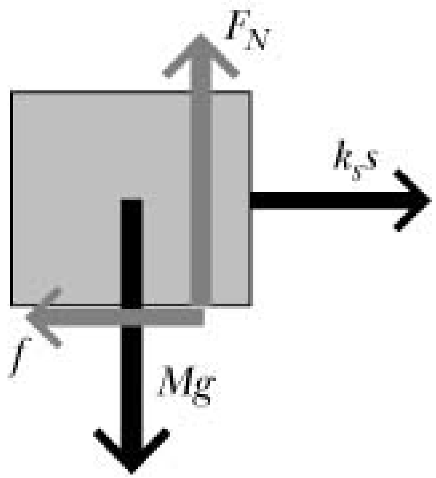
Complicated fluid dynamics!

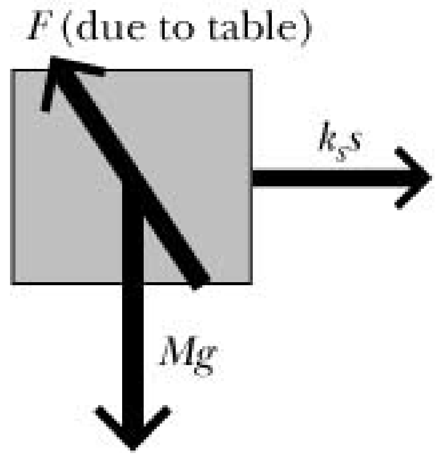


Sliding Friction

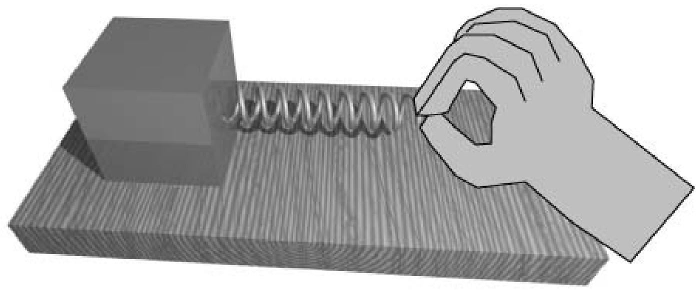


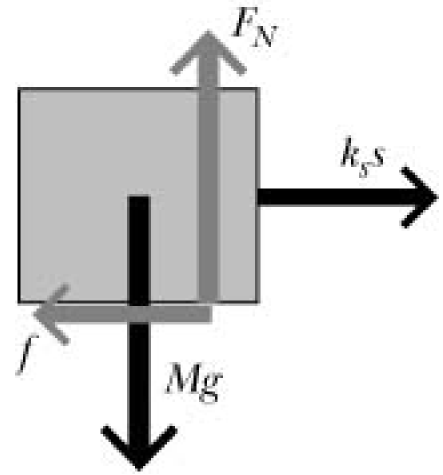
What forces act on the block as shown, being pulled across a table by the spring?

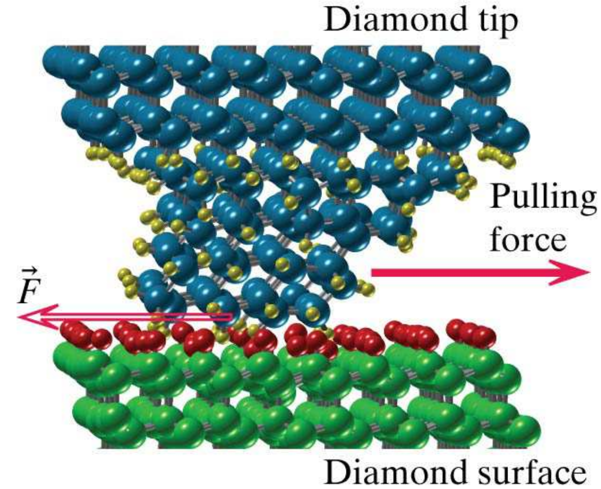




Sliding Friction





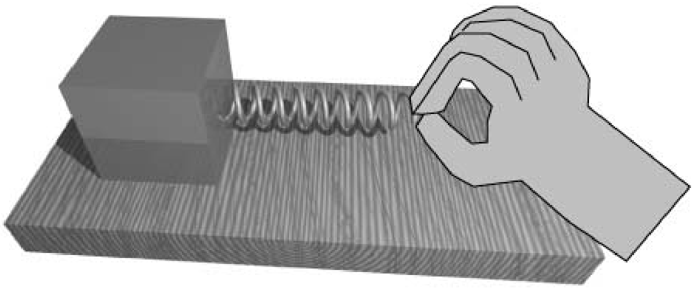


$$\boxed{f_{\max} \approx \mu F_N}$$

Approximate formula (not fundamental)

- doesn't apply to sticky surfaces (like tape)
- different materials have different values of μ
- coefficient of friction depends not only on material, but on its state – how dirty it is, etc.

Where did the energy go?



No increase in block's kinetic or potential energy.

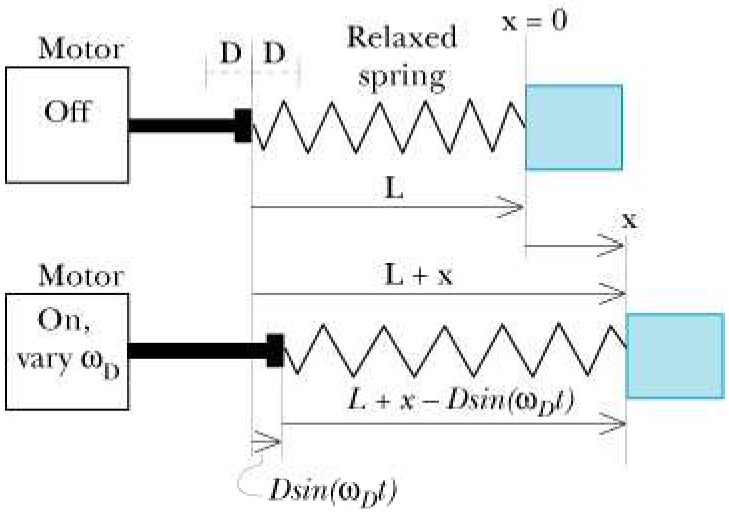
Macroscopically, we say it heats up the block & the table. Microscopically in increases the kinetic and potential energies of all the atoms involved (stretching the atomic springs).

Is it possible to reverse this process, to get the energy out of the many atoms involved and into motion of the block or stretching of the spring?

Physics in Your Life

Static Friction
Is Greater Than
Sliding Friction

Driven Oscillations



Oscillations damped by some viscous fluid:

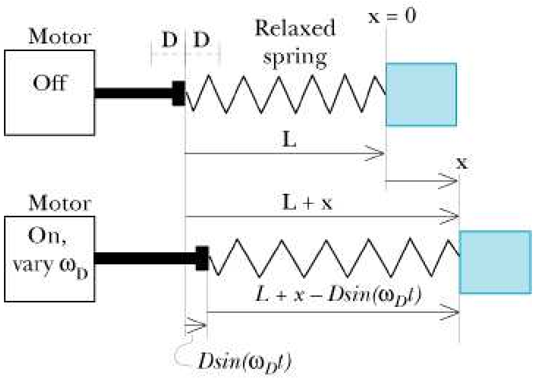
$$\vec{F}_{\text{viscous friction}} \approx -c\vec{v}$$

$$\frac{dp_x}{dt} = F_{\text{x,spring}} + F_{\text{x,friction}}$$

$$m\frac{d^2x}{dt^2} = -k_s\underbrace{[x - D\sin(\omega_D t)]}_{\text{“s” = the stretch}} - c\frac{dx}{dt}$$

How do you “solve” differential equations?

Driven Oscillations



$$\underbrace{m\frac{d^2x}{dt^2}+k_s\left[x-D\sin\left(\omega_D t\right)\right]+c\frac{dx}{dt}=0}$$

An inhomogeneous 2nd order linear differential equation. You'll study these in Math 266.

$$x = A\sin(\omega_D t + \phi)$$

Sinusoidal Motion

$$A=\frac{\omega_F^2}{\sqrt{\left(\omega_F^2-\omega_D^2\right)^2-\left(\frac{c}{m}\omega_D\right)^2}}D$$

With an interesting amplitude

Resonance

$$x = A\sin(\omega_D t + \phi)$$

$$A = \frac{\omega_F^2}{\sqrt{\left(\omega_F^2 - \omega_D^2\right)^2 - \left(\frac{c}{m}\omega_D\right)^2}} D$$

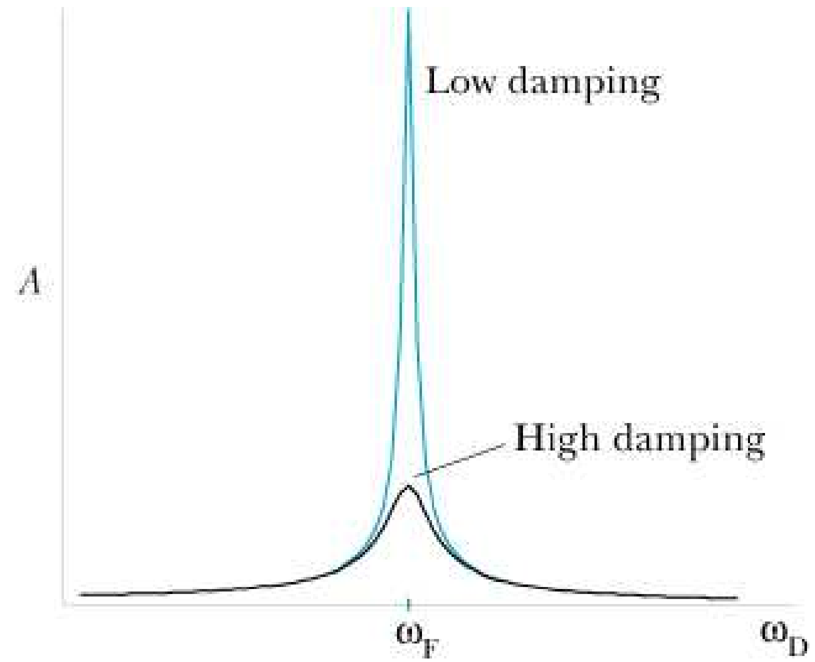
D=driving motor amplitude

A=amplitude of object

ω_F=free oscillation (natural) frequency

ω_D=driving frequency

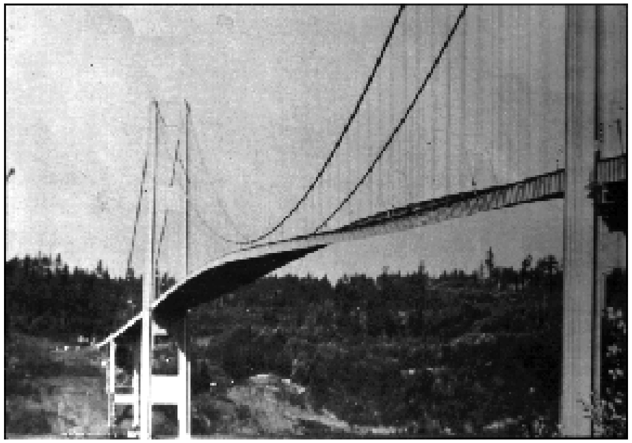
c=friction constant



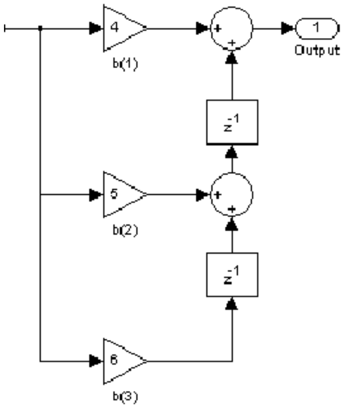
Want a big response? Drive it at the Resonant Frequency.

Don't want a big response? *Stay away from the Resonant Frequency!*

Two Examples of Resonance



Tacoma Narrows Bridge – resonant frequency of bridge matched that of neighboring wind patterns.



tuners and digital filters make use of resonance phenomena

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- Driven Oscillations and Resonance