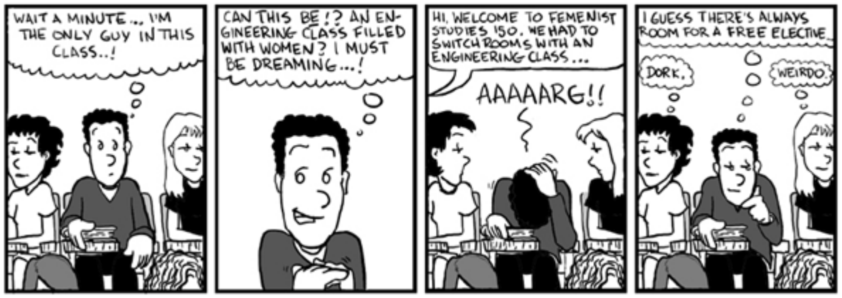
# engr14 – intro to solid mechanics




JORGE CHAM ©THE STANFORD DAILY

**tue/thu, 11:30-1:20pm, 550-200**



# engr14 – intro to solid mechanics

why do things break? to reliably predict what's going on inside a structure, we need to know the **forces** that act on it. it's **newton's law** that helps us to determine these forces. basically, this course is all about newton's law, force **equilibrium**, and its application to civil, mechanical, aerospace, and biological problems. we explore it for **particles** first, then for two-dimensional, and finally for three-dimensional **systems**. first we look at the structure from the **outside**, then from the **inside**. we learn how to identify, formulate, and solve engineering problems. to do so, you should be familiar with and not afraid of maths, vectors, and basic physics.

jean-cluade angles, kayla powers, josh siegel, jeanny wang, ellen kuhl

**tue/thu, 11:30-1:20pm, 550-200**



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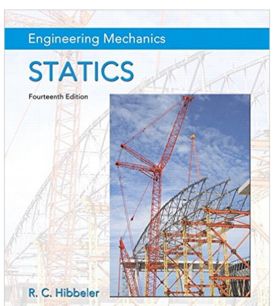
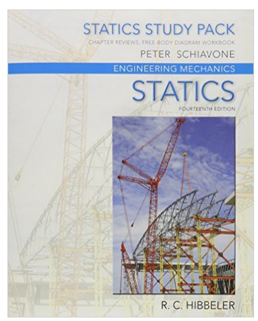



**textbook / e-textbook**

russell c. hibbeler
prentice hall, 14th edition

engineering mechanics
statics

statics study pack
for engineering mechanics




**textbook. russell c hibbeler: statics.**



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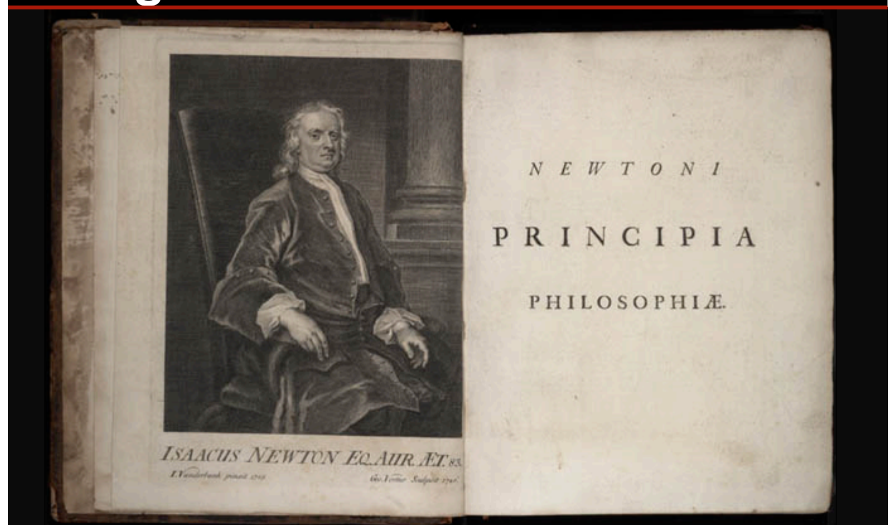
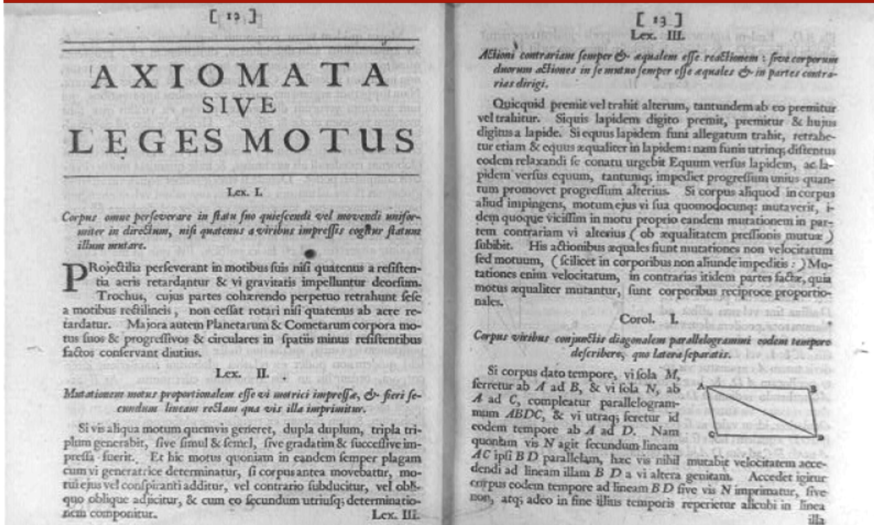



**... but our real bible is ...**




## … but our real bible is …



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LAW I.

*Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impress'd thereon.*

LAW II.

*The alteration of motion is ever proportional to the motive force impress'd; and is made in the direction of the right line in which that force is impress'd.*

LAW III.

*To every Action there is always opposed an equal Reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.*

philosophiae naturalis principia mathematica. isaac newton. [1687]

## newton's laws



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| Day | Date | Topic | Reading | HW due |
|---|---|---|---|---|
| | **W01** | **Force Week** | **Ch 1-2** | |
| Tue | 01/05 | What's statics? | 1.1-1.5 | |
| Thu | 01/07 | What's a force? | 2.1-2.9 | |
| | **W02** | **Particle Week** | **Ch 3** | |
| Tue | 01/12 | What's a free body diagram at a particle? | 3.1-3.2 | |
| Thu | 01/14 | What's force equilibrium at a particle? | 3.3-3.4 | HW1 |
| | **W03** | **Moment Week** | **Ch 4** | |
| Tue | 01/19 | What's a moment? | 4.1-4.4 | |
| Thu | 01/21 | What's a couple? What's distributed loading? | 4.5-4.7 | HW2 |
| | **W04** | **Practice Week** | **Ch 1-4** | |
| Tue | 01/26 | Problems, problems, problems… | 1.1-4.7 | |
| Thu | 01/28 | **Midterm 1**, in class, closed book, 1 cheat sheet | 1.1-4.7 | |
| | **W05** | **2d Equilibrium Week** | **Ch 5** | |
| Tue | 02/02 | What's a free body diagram of a 2d system? | 5.1-5.2 | |
| Thu | 02/04 | What's force and moment equilibrium in 2d? | 5.3-5.4 | HW3 |

## syllabus



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| | | | | |
|---|---|---|---|---|
| | **W06** | **3d Equilibrium Week** | **Ch 5** | |
| Tue | 02/09 | What's a free body diagram of a 3d system? | 5.5 | |
| Thu | 02/11 | What's force and moment equilibrium in 3d? | 5.6-5.7 | HW4 |
| | **W07** | **Structures Week** | **Ch 6** | |
| Tue | 02/16 | What's a truss? | 6.1-6.3 | |
| Thu | 02/18 | What's a frame? | 6.6 | HW5 |
| | **W08** | **Internal Force Week** | **Ch 7** | |
| Tue | 02/23 | What's a shear and moment diagram? | 7.1-7.3 | |
| Thu | 02/25 | **Midterm 2**, all day take home, Thu-Fri 2pm | 5.1-6.6 | |
| | **W09** | **Friction & Center Week** | **Ch 8-9** | |
| Tue | 03/01 | What's friction? | 8.1-8.2 | |
| Thu | 03/03 | What's the center? | 9.1-9.2 | |
| | **W10** | **That's it Week** | **Ch 1-9** | |
| Tue | 03/08 | The Last Lecture | 1.1-9.2 | |
| Thu | 03/10 | Problems, problems, problems… | 1.1-9.2 | |
| Wed | 03/16 | **Final**, in class, closed book, 1 cheat sheet | 1.1-9.2 | |

## syllabus

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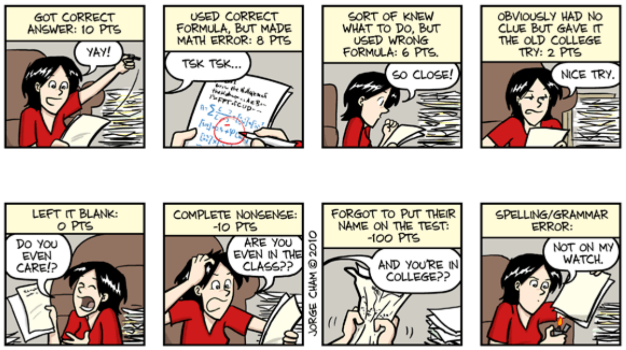


| | | |
|---|---|---|
| homework | 20 % | five homework assignments, 4% each |
| exams | 80 % | two midterms, one final, 30%, 25%, 25% each |
| final grade | ≥ 90 A range ≥ 80 B range ≥ 70 C range < 70 lower | |

## grades, grades, grades ...



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**homework.** homework sets will be announced in class and assigned via coursework. homework will be graded for completeness, correctness, and clarity. assignments must be completed in pencil on engineering computation paper. solutions must be legible and orderly, with complete and properly labeled free body diagrams. answers must be clearly boxed. the meaning of variables that you introduce must be clear. if the grader cannot read and follow your work, you will not get credit. you have up to three late days to use over the quarter. a late day is charged for any fraction of a day past the due date. once you have used your allocation of late days, further late submissions will be corrected, but will receive a score of zero. the final homework may not be submitted late

## grades, grades, grades ...



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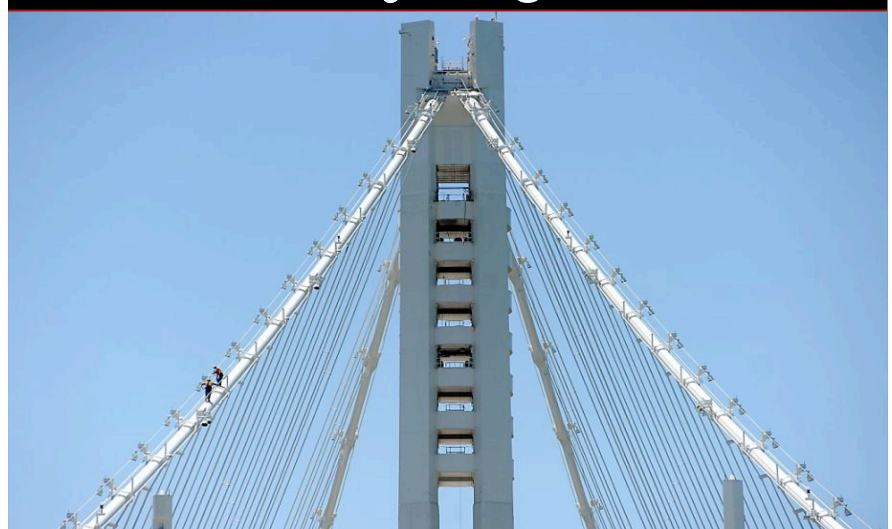
| | | |
|---|---|---|
| midterm 1 | thu, 01/28, in class | |
| midterm 2 | thu, 02/25, take home | |
| final exam | wed, 03/16, in class | |

**exams.** your highest exam score will count for 30% of your final grade and your other two exams will count for 25% each. the first midterm and the final are closed book/closed notes exams. you may bring one handwritten, letter sized formula sheet to each exam but no photocopies or printouts. the second midterm is a take home exam. you can use a calculator, but pre-programmed functions or programs may not be used. no internal or external communication is permitted during the exam. all exams must be taken at the scheduled time.

## grades, grades, grades ...



# bay bridge



## motivation – structural design

## bay bridge

motivation – structural design



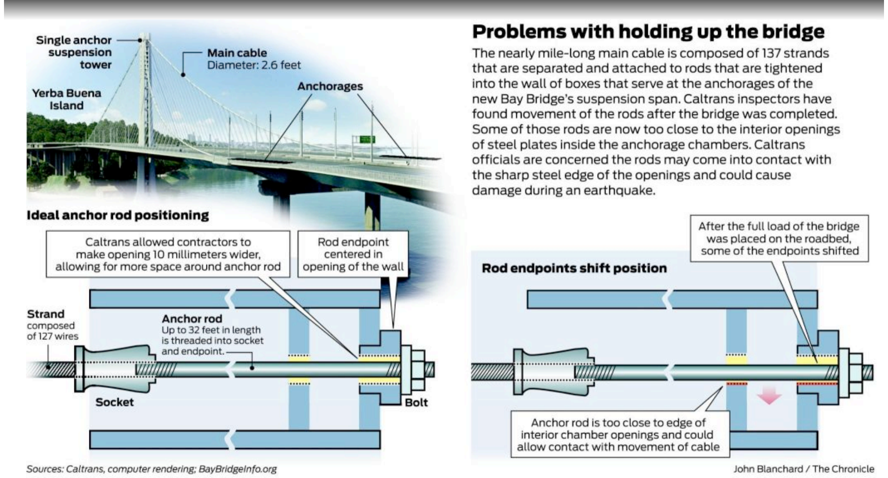
## bay bridge

news media at new eastern section of the bay bridge at pier e-2 which contains the found fractured anchor rods, as caltrans conducts a boat tour of the impacted areas of new eastern section of the bay bridge on march 27, 2013, in oakland, california. inspections earlier this month found that 30 large bolts on the new eastern span of the bay bridge have fractured.

motivation – structural design



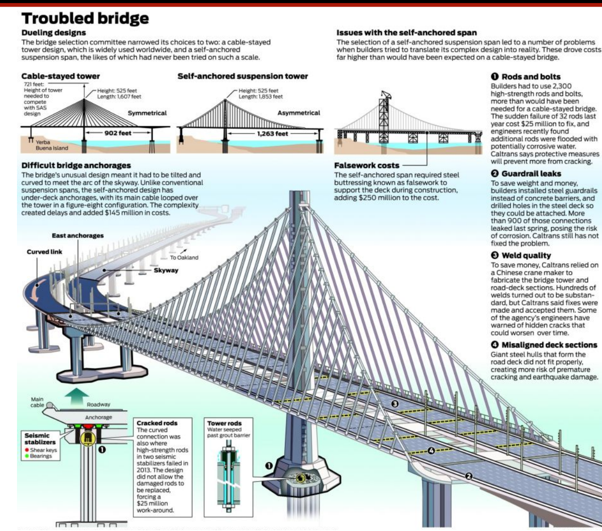
## bay bridge




motivation – structural design



## bay bridge




motivation – structural design

## structural failure

when a structure fails, there is invariably an investigation to find out why it failed. apart from the legal and professional necessity to determine the cause of failure, there is also the **need to learn from it** lessons that would enable subsequent designers and builders to avoid the pitfalls of the failed structure and **develop safer alternatives**.

technological developments in recent decades have introduced **new configurations**, **materials**, and **methods of design and construction** that raise new and complex problems. failures are caused by many unprecedented causes singly or in combination. paradoxially, in the pursuit of innovation, even **basic principles of sound structural design and good construction practice are often violated**, leading to failure.

krishnamurthy [2007]



## reasons for structural failure

| | |
|---|---|
| • **structural analysis** | 34% |
| • conceptual errors | 34% |
| • drawings and specifications | 19% |
| • work planning and preparation | 9% |
| • combinations | 4% |

| | |
|---|---|
| • **ignorance, carelessness, negligence** | 35% |
| • **insuffcent knowledge** | 25% |
| • **underestimation of influences** | 13% |
| • **forgetfulness, errors, mistakes** | 9% |
| • reliance upon others without sufficient control | 6% |
| • objectively unknown situation | 4% |
| • others | 8% |

matousek & schneider [1976], krishnamurthy [2007]



## reasons for structural failure

| | |
|---|---|
| **sudden failure, subtotal** | **66%** |
| • loss of equilibrium | 13% |
| • failure with collapse | 29% |
| • failure without collapse | 11% |
| • other types of failure | 10% |
| | |
| **unacceptable conditions, subtotal** | **33%** |
| • excessive cracks | 16% |
| • errors in dimensions and support conditions | 8% |
| • deflections and change of shape | 7% |
| • other unacceptable conditions | 6% |

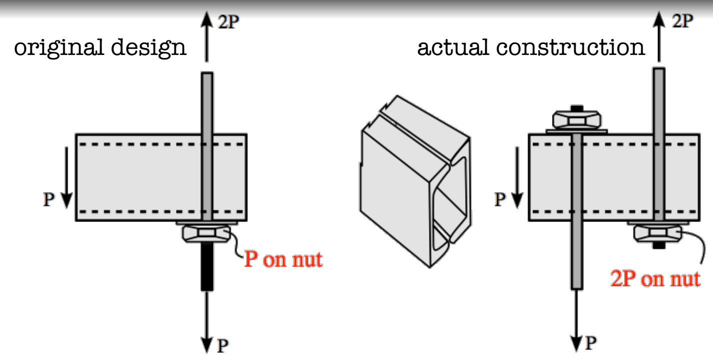
krishnamurthy [2007]



## hyatt regencey walkway collapse

the hyatt regency hotel walkway collapse occurred on july 17, 1981, in kansas city, missouri, killing 114 people and injuring 216 others. at the time, it was the deadliest structural collapse of u.s. history. one of the defining features of the hotel was its lobby, which featured a multistory atrium spanned by steel, glass and concrete walkways on the second, third and fourth levels suspended from the ceiling. the walkways were 37m long and weighed 29,000 kg. the fourth level walkway aligned directly above the second level walkway.

## hyatt regencey walkway collapse




construction difficulties resulted in a subtle but flawed design change that doubled the load on the connection between the walkway support beams and the tie rods carrying the weight of the second and fourth floor walkways. this excessive load caused a lower bold to pull through the beam so that the upper walkway collapsed upon the one below.



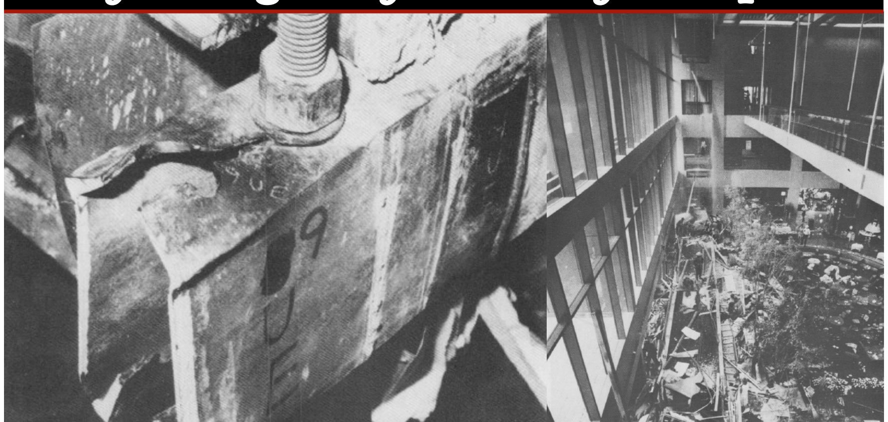
## hyatt regencey walkway collapse

the engineers who had approved the final drawings were convicted by the missouri board of architects, profes-sional engineers, and land surveyors of gross negligence, misconduct, and unprofessional conduct in the prac-tice of engineering; they all lost their engineering licenses in the state of missouri and texas. while the design company was discharged of criminal negligence, it lost its license to be an engineering firm. at least $140 million was awarded to victims and their families in civil lawsuits.

ethics in engineering practise & research. whitbeck [1998]



## hyatt regencey walkway collapse

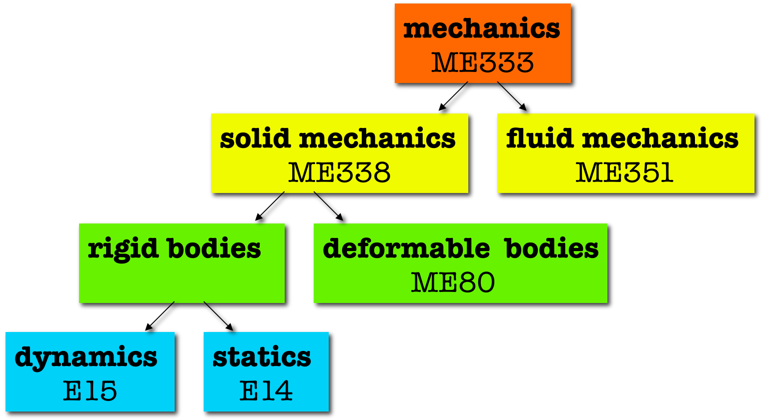


the hyatt regency tragedy remains a classic model for the study of engineering ethics and errors. “investigation of the kansas city hyatt regency walkway collapse” us department of commerce [1982]



## collapse of  the pregnant oyster

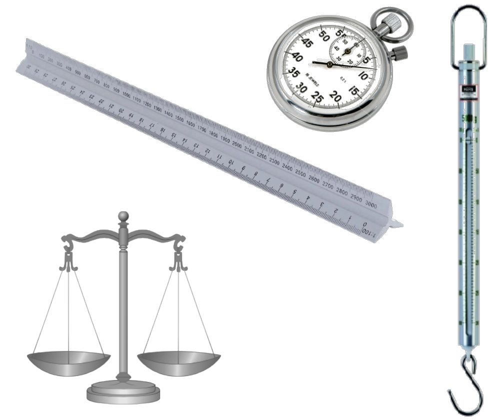
## mechanics






## basic quantities

- **length.** meter [m]
- **time.** second [s]
- **mass.** gram [g]
- **force.** newton [N]



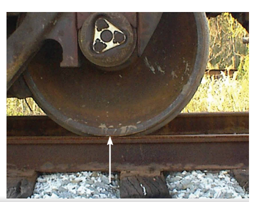


## idealizations

**particle.** a particle has a finite mass but a size that can be neglected. for example, the size of the earth is insignificant compare to the size of the orbit; therefore the earth can be modeled as a particle when studying planet motion.

**rigid body.** a rigid body is a combination of a large number of particles with all particles remaining at a fixed distance from one another.

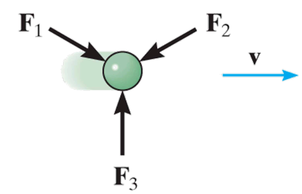
**concentrated force.** a concentrated force is a representation of loading as a single point force. this is justified if the load is applied to an area which is small compared to the overall size of the body.



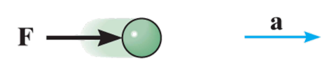


## newton 's three laws of motion

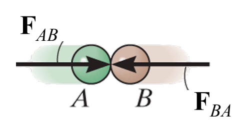
- first law
  equilibrium
  if $\sum \boldsymbol{F} = \boldsymbol{0}$ then $\boldsymbol{v} = \text{const.}$




- second law
  accelerated motion
  $\boldsymbol{F} = \boldsymbol{m} \cdot \boldsymbol{a}$




- third law
  actio = reactio
  $\boldsymbol{F}_{AB} = - \boldsymbol{F}_{BA}$



# weight

**SI system**

$W = m \cdot g$

$W$ ... weight (derived quantity)

$m$ ... mass (basic quantity)

$g$ ... acceleration due to gravity

$g = 9.81\ \mathrm{m/s^2}$

**FPS system**

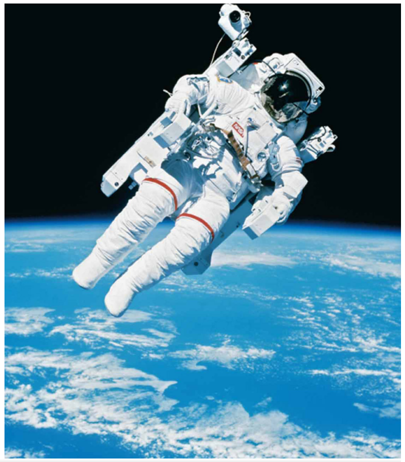
$m = W / g$

$m$ ... mass (derived quantity)

$W$ ... weight (basic quantity)

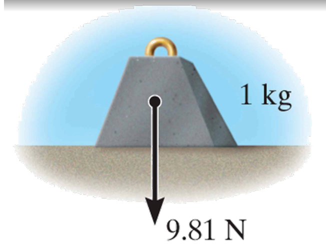
$g$ ... acceleration due to gravity

$g = 32.2\ \mathrm{ft/s^2}$





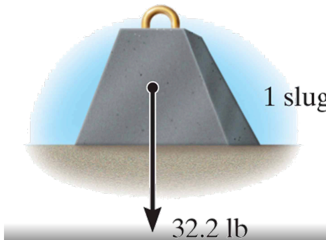
# systems of units




**SI system**

basic units
- meters [m]
- seconds [s]
- kilogram [kg]

derived unit
- Newton [$\mathrm{N = kg \cdot m / s^2}$]




**FPS system**

basic units
- feet [ft]
- seconds [s]
- pounds [lb]

derived unit
- slug [$\mathrm{slug = lb \cdot s^2/ft}$]



# systems of units

**TABLE 1–1 Systems of Units**

| Name | Length | Time | Mass | Force |
|---|---|---|---|---|
| International System of Units SI | meter<br>m | second<br>s | kilogram<br>kg | newton*<br>N<br>$\left(\frac{\mathrm{kg \cdot m}}{\mathrm{s^2}}\right)$ |
| U.S. Customary FPS | foot<br>ft | second<br>s | slug*<br>$\left(\frac{\mathrm{lb \cdot s^2}}{\mathrm{ft}}\right)$ | pound<br>lb |

*Derived unit.



# conversion of units

**TABLE 1.2 Conversion Factors**

| Quantity | Unit of Measurement (FPS) | Equals | Unit of Measurement (SI) |
|---|---|---|---|
| Force | lb | | 4.448 N |
| Mass | slug | | 14.59 kg |
| Length | ft | | 0.304 8 m |

# prefixes

**TABLE 1.3 Prefixes**

| | Exponential Form | Prefix | SI Symbol |
|---|---|---|---|
| *Multiple* | | | |
| 1 000 000 000 | $10^9$ | giga | G |
| 1 000 000 | $10^6$ | mega | M |
| 1 000 | $10^3$ | kilo | k |
| *Submultiple* | | | |
| 0.001 | $10^{-3}$ | milli | m |
| 0.000 001 | $10^{-6}$ | micro | $\mu$ |
| 0.000 000 001 | $10^{-9}$ | nano | n |



# after the break...