Dynamics of Potentials and Force Fields
(Ch. 7 and Ch. 8 of Unit 1)

Potential energy geometry of Superballs and related things

Thales geometry and “Sagittal approximation”

Geometry and dynamics of single ball bounce

Examples: (a) Constant force (like kidee pool) (b) Linear force (like balloon)

Some physics of dare-devil-divers

Non-linear force (like superball-floor or ball-bearing-anvil)

Geometry and dynamics of 2-ball bounce (again with feeling)

The parable of RumpCo. vs CrapCorp.

The story of USC pre-meds visiting Whammo Manufacturing Co.

Geometry and dynamics of 3-ball bounce

A story of Stirling Colgate (Palmolive) and core-collapse supernovae

The story of USC pre-meds visiting Whammo Manufacturing Co.

Other bangings-on: The western buckboard and Newton’s balls

Crunch energy geometry of freeway crashes and related things

Crunch energy played backwards: This really is “Rocket-Science”

A Thales construction for momentum-energy

Lecture 5 ends here
Potential energy geometry of Superballs and related things

Thales geometry and “Sagittal approximation”

Geometry and dynamics of single ball bounce
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Potential Energy Geometry of Superballs and Related things

If superball was a balloon its bounce force law would be linear $F = -k \cdot x$ (Hooke Law)

$$F_{\text{balloon}}(x) = P \cdot A = P \cdot \pi r^2 \approx 2\pi PRx$$
If superball was a balloon its bounce force law would be linear $F = -k \cdot x$ (Hooke Law)

$$F_{\text{balloon}}(x) = P \cdot A = P \cdot \pi r^2 \approx 2\pi PRx$$

Instead superball force law depends on bulk *volume* modulus and is non-linear $F \sim x^p$? +? (Power Law?)

$$Volume(X) = \int_0^X \pi r^2 \, dx = \int_0^X \pi x(2R - x) \, dx = \int_0^X 2R\pi x \, dx - \int_0^X \pi x^2 \, dx = R\pi X^2 - \frac{\pi X^3}{3} \approx \begin{cases} R\pi X^2 & \text{for } X \ll R \\ \frac{4}{3} \pi R^3 & \text{for } X = 2R \end{cases}$$

It also depends on velocity $\dot{x} = \frac{dx}{dt}$. *Adiabatic* differs from *Isothermal* as shown by “*Project-Ball*”

Potential energy geometry of Superballs and related things

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Geometry and dynamics of single ball bounce  (See Simulation)

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Other bangings-on: The western buckboard and Newton’s balls
Total energy \( E = mgh \)

(a) Drop height

Drop height
(Zero kinetic energy)

Floor force balances weight mg

(b) Maximum kinetic energy

Maximum kinetic energy
(Zero total force)

Force is zero

(c) Maximum penetration

Maximum penetration
(Zero kinetic energy again)
(See Simulation)

- Let mouse set: \((x,y,V_x,V_y)\)
- Let mouse set force: \(F(t)\)
- Plot solid paths
- Plot dotted paths
- Plot no paths
- Plot \(V_1\) vs. \(V_2\)
- Plot \(Y_1(t), Y_2(t), \ldots\)
- Plot \(PE\) of \(m_1\) vs. \(Y_1\)
- Plot \(Y_2\) vs. \(Y_1\)
- Plot user defined i.e. \(Y_1\) vs. \(Y_2\)
- Balls initially falling
- Balls initially fixed
- No preset initial values

Number of masses

\[
\begin{array}{c|c}
\text{Balls} & 1 & 1 \\
\end{array}
\]

Initial gap between balls

\[
\begin{array}{c|c}
\text{cm} & 0 & 0 \\
\end{array}
\]

Acceleration of gravity

\[
100 \times [\text{cm/s}^2]
\]

Force power law exponent

\[
\begin{array}{c|c}
\text{4} & 4 \\
\end{array}
\]

Collision friction (Viscosity)

\[
\begin{array}{c|c}
\text{0} & 0 \\
\end{array}
\]

- Draw force vectors
- Pause (once) at top
- Constrain motion to \(Y\)-axis

Initial \(V = \)

\[
\begin{array}{c|c}
\text{0} & 0 \\
\end{array}
\]

\(y\) Max = \(4\)

\(y\) Min = \(-3\)

Max \(x\) PE plot

\[
\begin{array}{c|c}
\text{0.5} & 0.5 \\
\end{array}
\]

\(T\) Max = \(6\)

F-Vector scale

\[
\begin{array}{c|c}
\text{0.003} & 0.003 \\
\end{array}
\]

\(V_2y\) Max = \(3\)

\(V_2y\) Min = \(-2\)

Error step

\[
\begin{array}{c|c}
\text{0.000001} & 0.000001 \\
\end{array}
\]

1st Mass \(m_1 = \)

\[
\begin{array}{c|c}
\text{100} & \{\text{g}\} \\
\end{array}
\]

1st Mass \(V_1 = \)

\[
\begin{array}{c|c}
\text{0} & \{\text{cm/s}\} \\
\end{array}
\]
(a) Drop height $h$ (Zero kinetic energy)

Total potential energy curve $U(x) + mgY$

Total energy $E = mgh$

Force is weight $mg$ only

Display of Force vector using similar triangle construction based on the slope of potential curve.
(b) Maximum kinetic energy
(Zero total force)
(c) Maximum penetration
(Zero kinetic energy again)
(a) Drop height $h$
(Zero kinetic energy)

(b) Maximum kinetic energy
(Zero total force)

(c) Maximum penetration
(Zero kinetic energy again)

Display of Force vector using similar triangle construction based on the slope of potential curve.
Force $F(x)$ and Potential $U(x)$ for soft heavy non-linear superball

$F_{\text{total}}(y) = -Mg + F_{\text{ball}}(y)$

$U_{\text{total}}(y) = -Mgx + U_{\text{ball}}(y)$

Total Energy $E = Mg\cdot h$

$U_{\text{total}}(y_{\text{max}}) = \int_{y_{\text{static}}}^{y_{\text{max}}} F_{\text{total}}(y) \, dy + \int_{y_{\text{static}}}^{y_{\text{max}}} F_{\text{total}}(y) \, dy + U(h) = U(h) = E$

$F(x) = -\frac{dU(x)}{dx}$
**Force** $F(x)$ and **Potential** $U(x)$ for soft heavy non-linear superball

\[
F_{\text{total}}(y) = -Mg + F_{\text{ball}}(y)
\]

\[
U_{\text{total}}(y) = -Mgx + U_{\text{ball}}(y)
\]

**Total Energy** $E = Mg\,h$

\[
U_{\text{total}}(y_{\max}) = \int_{y_{\text{static}}}^{y_{\max}} F_{\text{total}}(y) \, dy + \int_{y=h}^{y_{\text{static}}} F_{\text{total}}(y) \, dy + U(h) = U(h) = E
\]

**Work** $W = \int F(x) \, dx = \text{Energy acquired} = \text{Area of} \ F(x) = -U(x)$

\[
F(x) = -\frac{dU(x)}{dx}
\]
Force \( F(x) \) and Potential \( U(x) \) for soft heavy non-linear superball

\[
U_{\text{total}}(y) = -Mg + U^{\text{ball}}(y)
\]

\[
F_{\text{total}}(y) = -Mg + F^{\text{ball}}(y)
\]

Total Energy \( E = Mg \)

\[
W = \int F(x)\,dx = \text{Energy acquired} = \text{Area of } F(x) = -U(x)
\]

\[
F(x) = -\frac{dU(x)}{dx}
\]

\[
I = \int F(t)\,dt = \text{Momentum acquired} = \text{Area of } F(t) = P(t)
\]

\[
F(t) = \frac{dP(t)}{dt}
\]
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Thales geometry and “Sagittal approximation”
Geometry and dynamics of single ball bounce

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Other hangings-on: The western buckboard and Newton’s balls
**Work** = \( W = \int F(x) \, dx = \text{Energy acquired} = \text{Area of } F(x) = -U(x) \)

\[ F(x) = -\frac{dU(x)}{dx} \]

**Impulse** = \( P = \int F(t) \, dt = \text{Momentum acquired} = \text{Area of } F(t) = P(t) \)

\[ F(t) = \frac{dP(t)}{dt} \]
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Other bangings-on: The western buckboard and Newton’s balls
(a) Force $F(Y) \, \text{Units} \, Mg \, (N)$

- Strongly increasing Force
  $f(y) = 16y - 1$

- Gentle Constant Gravity Force
  $f(y) = -2y - 1$

(b) Potential $U(Y) \, \text{Units of} \, MgY \, (J)$

- Rapidly growing slope
  $u(y) = 8y^2 + y$

- Gentle constant slope (Pure gravity)
  $u(y) = y$

(c) Force $F(Y) \, \text{Units} \, Mg \, (N)$

- Gentle Constant Gravity Force
  $f(y) = -2y - 1$

(d) Potential $U(Y) \, \text{Units of} \, MgY \, (J)$

- Growing slope
  $u(y) = y^2 + y$

(e) Geometry of Linear Force with Constant $Mg$ and Quadratic Potential

- $F(Y) = -kY \cdot Mg$

- $U(Y) = (1/2)kY^2 + Mg \cdot Y$

Unit 1

![Fig. 7.4](image)

$$F_{Total} = F_{grav} + F_{target} = \begin{cases} -Mg & (y \geq 0) \\ -Mg - ky & (y < 0) \end{cases}$$

$$U_{Total} = U_{grav} + U_{target} = \begin{cases} Mg \cdot y & (y \geq 0) \\ Mg \cdot y + \frac{1}{2}ky^2 & (y < 0) \end{cases}$$
Let mouse set: \((x,y,Vx,Vy)\)
Let mouse set force: \(F(t)\)

- Plot solid paths
- Plot dotted paths
- Plot no paths
- Plot \(V_1(t)\), \(Y_2(t)\), ...
- Plot PE of \(m_1\) vs. \(Y_1\)
- Plot \(Y_2\) vs. \(Y_1\)
- Plot user defined i.e - \(Y_1\) vs. \(Y_2\)
- Balls initially falling
- Balls initially fixed
- No preset initial values

Number of masses:

|   |   | Balls
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
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</table>

Initial gap between balls:

|   |   | cm
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
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</table>

Acceleration of gravity:

|   |   | \(100 \times \text{cm/s}^2\)
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>2</td>
<td>2</td>
<td></td>
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</table>

Collision friction (Viscosity):

<p>| | |</p>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
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</table>

- Draw force vectors
- Pause (once) at top
- Constrain motion to Y-axis

Force power law exponent:

|   |   | 1
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<tbody>
<tr>
<td>1</td>
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Force Constant:

|   |   | 2000, 2000
<table>
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<tr>
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<tbody>
<tr>
<td>2000</td>
<td>2000</td>
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Canvas Aspect Ratio - W/H i.e. 0.75 & 1.0:

|   |   | 1, 1
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Initial \(V\) =

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Initial \(x_1\) =

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<tr>
<td>0.01</td>
<td>0.01</td>
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Max \(x\) PE plot =

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<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
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F-Vector scale =

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<tbody>
<tr>
<td>0.003</td>
<td>0.003</td>
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Error step =

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<tr>
<td>0.000001</td>
<td>0.000001</td>
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\(y\) Max =

|   |   | 7
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<tbody>
<tr>
<td>7</td>
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\(y\) Min =

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<tr>
<td>0</td>
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\(T\) Max =

|   |   | 6
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<tbody>
<tr>
<td>6</td>
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\(V_2y\) Max =

|   |   | 3
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<tr>
<td>3</td>
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\(V_2y\) Min =

|   |   | -2
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<tr>
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1st Mass \(m_1\) =

|   |   | \(100 \{g\}\)
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<tr>
<td>100</td>
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1st Mass \(V_1\) =

|   |   | \(-1 \{\text{cm/s}\}\)
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<td>-1</td>
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</tbody>
</table>
Potential energy geometry of Superballs and related things

Thales geometry and “Sagittal approximation”

Geometry and dynamics of single ball bounce

Examples: (a) Constant force (like kidee pool) (b) Linear force (like balloon)

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$U_{\text{total}}(y) = -Mgx + U_{\text{ball}}(y)$

Total Energy $E = Mg_h$

$U_{\text{total}}(y_{\text{max}}) = \int_{y_{\text{static}}}^{y_{\text{max}}} F_{\text{total}}(y) \, dy + \int_{y=h}^{y_{\text{static}}} F_{\text{total}}(y) \, dy + U(h) = U(h) = E$

Work $= W = \int F(x) \, dx = \text{Energy acquired} = \text{Area of } F(x) = -U(x)$

$F(x) = -\frac{dU(x)}{dx}$

Impulse $= P = \int F(t) \, dt = \text{Momentum acquired} = \text{Area of } F(t) = P(t)$

$F(t) = \frac{dP(t)}{dt}$

Friday, December 21, 2012
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Unit 1
Fig. 7.6
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   Other bangings-on: The western buckboard and Newton’s balls
(a) Quartic Force
\[ F(y) = k y^4 \]

Initial Velocities

\[ \begin{align*}
\dot{v}_1 &= -1 \text{ m/s} \\
\dot{v}_2 &= -1 \text{ m/s} \\
\dot{v}_3 &= -1 \text{ m/s}
\end{align*} \]

Final Velocities

\[ \begin{align*}
\dot{v}_1 &= -1 \text{ m/s} \\
\dot{v}_2 &= 0.701 \text{ m/s} \\
\dot{v}_3 &= 3.41 \text{ m/s}
\end{align*} \]

(b) Independent Collisions (Independent of Force Law)

Initial Velocities

\[ \begin{align*}
\dot{v}_1 &= -1 \text{ m/s} \\
\dot{v}_2 &= -1 \text{ m/s} \\
\dot{v}_3 &= -1 \text{ m/s}
\end{align*} \]

Final Velocities

\[ \begin{align*}
\dot{v}_1 &= 0.077 \text{ m/s} \\
\dot{v}_2 &= 0.538 \text{ m/s} \\
\dot{v}_3 &= 3.62 \text{ m/s}
\end{align*} \]

(c) Linear Force
\[ F(y) = k y \]

Initial Velocities

\[ \begin{align*}
\dot{v}_1 &= -1 \text{ m/s} \\
\dot{v}_2 &= -1 \text{ m/s} \\
\dot{v}_3 &= -1 \text{ m/s}
\end{align*} \]

Final Velocities

\[ \begin{align*}
\dot{v}_1 &= 0.81 \text{ m/s} \\
\dot{v}_2 &= 1.32 \text{ m/s} \\
\dot{v}_3 &= 1.48 \text{ m/s}
\end{align*} \]
(a) Quartic Force
\[ F(y) = k y^4 \]
\[
\begin{align*}
m_3 &= 10 \text{ kg} \\
m_2 &= 30 \text{ kg} \\
m_1 &= 100 \text{ kg}
\end{align*}
\]
Initial Velocities
\[
\begin{align*}
V_3 &= -1 \text{ m/s} \\
V_2 &= -1 \text{ m/s} \\
V_1 &= -1 \text{ m/s}
\end{align*}
\]
Final Velocities
\[
\begin{align*}
V_3 &= 3.41 \text{ m/s} \\
V_2 &= 0.701 \text{ m/s} \\
V_1 &= 0.298 \text{ m/s}
\end{align*}
\]

(b) Independent Collisions (Independent of Force Law)

(c) Linear Force
\[ F(y) = ky \]
\[
\begin{align*}
m_3 &= 10 \text{ kg} \\
m_2 &= 30 \text{ kg} \\
m_1 &= 100 \text{ kg}
\end{align*}
\]
Initial Velocities
\[
\begin{align*}
V_3 &= -1 \text{ m/s} \\
V_2 &= -1 \text{ m/s} \\
V_1 &= -1 \text{ m/s}
\end{align*}
\]

Unit 1
Fig. 8.1b
Independent Bang Model (IBM)
3-Body Geometry

\[ V_{up} \]
\[ Bang(3)_{23} \]
\[ END (0.54, 3.62) \]
\[
\begin{align*}
m_3 &= 10 \\
m_2 &= 30 \\
m_1 &= 100
\end{align*}
\]

\[ V_{down} \]
\[ Bang(2)_{12} \]
\[ END (0.77, 2.1) \]
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Source
http://hubblesite.org/newscenter/archive/releases/2007/10/image/a/

Author
NASA, ESA, P. Challis, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)

### Core-burning nuclear fusion stages for a 25-solar mass star

<table>
<thead>
<tr>
<th>Process</th>
<th>Main fuel</th>
<th>Main products</th>
<th>Temperature (Kelvin)</th>
<th>Density (g/cm³)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogen burning</td>
<td>hydrogen</td>
<td>helium</td>
<td>7×10⁷</td>
<td>10</td>
<td>10⁷ years</td>
</tr>
<tr>
<td>triple-alpha process</td>
<td>helium</td>
<td>carbon, oxygen</td>
<td>2×10⁸</td>
<td>2000</td>
<td>10⁶ years</td>
</tr>
<tr>
<td>carbon burning process</td>
<td>carbon</td>
<td>Ne, Na, Mg, Al</td>
<td>8×10⁸</td>
<td>10⁶</td>
<td>10³ years</td>
</tr>
<tr>
<td>neon burning process</td>
<td>neon</td>
<td>O, Mg</td>
<td>1.6×10⁹</td>
<td>10⁷</td>
<td>3 years</td>
</tr>
<tr>
<td>oxygen burning process</td>
<td>oxygen</td>
<td>Si, S, Ar, Ca</td>
<td>1.8×10⁹</td>
<td>10⁷</td>
<td>0.3 years</td>
</tr>
<tr>
<td>silicon burning process</td>
<td>silicon</td>
<td>nickel (decays into iron)</td>
<td>2.5×10⁹</td>
<td>10⁸</td>
<td>5 days</td>
</tr>
</tbody>
</table>
A story of Stirling Colgate (Palmolive) and core-collapse supernovae

Source
http://hubblesite.org/newscenter/archive/releases/2007/10/image/a/

Author
NASA, ESA, P. Challis, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)

Core-burning nuclear fusion stages for a 25-solar mass star

<table>
<thead>
<tr>
<th>Process</th>
<th>Main fuel</th>
<th>Main products</th>
<th>Temperature (Kelvin)</th>
<th>Density (g/cm³)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogen burning</td>
<td>hydrogen</td>
<td>helium</td>
<td>$7 \times 10^7$</td>
<td>10</td>
<td>$10^7$ years</td>
</tr>
<tr>
<td>triple-alpha process</td>
<td>helium</td>
<td>carbon, oxygen</td>
<td>$2 \times 10^8$</td>
<td>2000</td>
<td>$10^8$ years</td>
</tr>
<tr>
<td>carbon burning process</td>
<td>carbon</td>
<td>Ne, Na, Mg, Al</td>
<td>$8 \times 10^6$</td>
<td>$10^6$</td>
<td>$10^3$ years</td>
</tr>
<tr>
<td>neon burning process</td>
<td>neon</td>
<td>O, Mg</td>
<td>$1.6 \times 10^8$</td>
<td>$10^7$</td>
<td>3 years</td>
</tr>
<tr>
<td>oxygen burning process</td>
<td>oxygen</td>
<td>Si, S, Ar, Ca</td>
<td>$1.8 \times 10^8$</td>
<td>$10^7$</td>
<td>0.3 years</td>
</tr>
<tr>
<td>silicon burning process</td>
<td>silicon</td>
<td>nickel (decays into iron)</td>
<td>$2.5 \times 10^9$</td>
<td>$10^8$</td>
<td>5 days</td>
</tr>
</tbody>
</table>

Within a massive, evolved star (a), the onion-layered shells of elements undergo fusion, forming a nickel-iron core (b) that reaches Chandrasekhar mass and starts to collapse. The inner part of the core is compressed into neutrons (c), causing infalling material to bounce (d) and form an outward-propagating shock front (red). The shock stalls (e), but it is re-invigorated by neutrino interaction. The surrounding material is blasted away (f), leaving only a degenerate remnant.
Potential energy geometry of Superballs and related things

Thales geometry and “Sagittal approximation”

Geometry and dynamics of single ball bounce

Examples: (a) Constant force (like kidee pool) (b) Linear force (like balloon)

Some physics of dare-devil-divers

Non-linear force (like superball-floor or ball-bearing-anvil)

Geometry and dynamics of 2-ball bounce (again with feeling)

The parable of RumpCo. vs CrapCorp.

The story of USC pre-meds visiting Whammo Manufacturing Co.

Geometry and dynamics of 3-ball bounce

A story of Stirling Colgate (Palmolive) and core-collapse supernovae

Other bangings-on: The western buckboard and Newton’s balls
Unit 1

Fig. 8.2a-b
4-Body IBM Geometry

Fig. 8.2c-d
4-Equal-Body Geometry

(c) Bouncing column
\[ m_k/m_{k+1} = 1 \]

(d) Single pop-up
\[ (0,1) \]
Crunch energy geometry of freeway crashes and related things
Crunch energy played backwards: This really is “Rocket-Science”
Unit 1

Fig. 8.5

Pile-up:
One 60mph car hits five standing cars
Fig. 8.5
Pile-up:
One 60mph car
hits
five standing cars

Fig. 8.6
Pile-up:
Five 60mph cars
hit
one standing cars
Fig. 8.5
Pile-up:
One 60mph car
hits
five standing cars

Fig. 8.6
Pile-up:
Five 60mph cars
hit
one standing cars

Fig. 8.7
Pile-up:
Five 60mph cars
hit
five standing cars

(Fug-gedda-aboud-dit!!)
Crunch energy geometry of freeway crashes and related things

Crunch energy played backwards: This really is “Rocket-Science”
Rocket Science!
By calculus: $M \cdot \Delta V = -v_e \cdot \Delta M$  

or: $dV = -v_e \frac{dM}{M}$  

Integrate: $\int_{V_{IN}}^{V_{FIN}} dV = -v_e \int_{M_{IN}}^{M_{FIN}} \frac{dM}{M}$  

The Rocket Equation: $V_{FIN} - V_{IN} = -v_e \left[ \ln M_{FIN} - \ln M_{IN} \right] = v_e \left[ \ln \frac{M_{IN}}{M_{FIN}} \right]$
A Thales construction for momentum-energy
(a) Draw $m_2 : m_1$ box in 1st quadrant.

(b) Using $m_2$ arc copy $m_2 : m_1$ box into 2nd quadrant.

(c) Locate center of extended box and draw arc from its top to top of $m_2 : m_1$ box. This locates $\sqrt{m_2 \cdot m_1}$ slope.

(d) Projections from $v_{COM}$ to $v_{m_2 \cdot m_1}$ line give COM-ellipse radii $a_{COM}$ and $b_{COM}$.

(e) Projections from $v_{START}$ to $v_{m_2 \cdot m_1}$ line give START-ellipse radii $a_{START}$ and $b_{START}$.