Lecture 5
Tue. 9.8.2015

Dynamics of Potentials and Force Fields

(Ch. 7 and part of Ch. 8 of Unit 1)

Potential energy dynamics of Superballs and related things

Thales geometry and "Sagittal approximation" to superball force law
Geometry and dynamics of single ball bounce
(a) Constant force F=-k (linear potential V=kx)
Some physics of dare-devil diving 80 ft. into kidee pool
(b) Linear force F=-kx (quadratic potential $V=\frac{1}{2}kx^2$ (like balloon))
(c) Non-linear force (like superball-floor or ball-bearing-anvil)

Geometry and potential dynamics of 2-ball bounce

A parable of RumpCo. vs CrapCorp. (introducing 3-mass potential-driven dynamics)
A story of USC pre-meds visiting Whammo Manufacturing Co.

Geometry and dynamics of n-ball bounces

Analogy with shockwave and acoustical horn amplifier
Advantages of a geometric m_1, m_2, m_3,... series
A story of Stirling Colgate (Palmolive) and core-collapse supernovae

Many-body 1D collisions

Elastic examples: Western buckboard
Bouncing columns and Newton's cradle
Inelastic examples: "Zig-zag geometry" of freeway crashes
Super-elastic examples: This really ***is*** *"Rocket-Science"*

Potential energy dynamics of Superballs and related things

→ *Thales geometry and "Sagittal approximation" to force law*

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

Constant force F=-k (linear potential V=kx)

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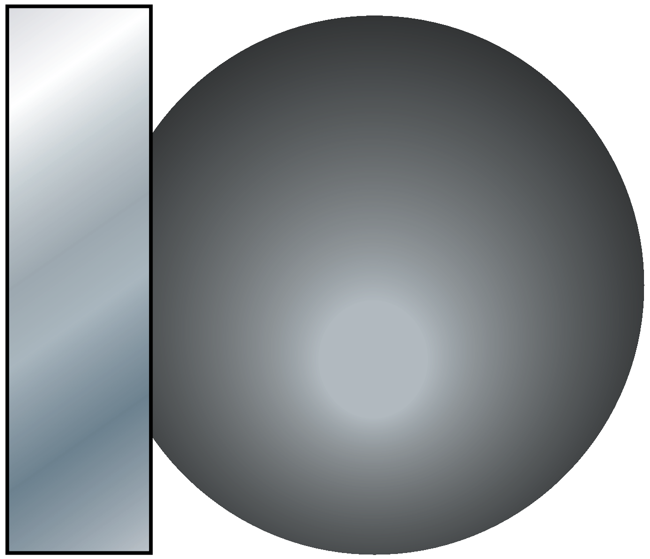
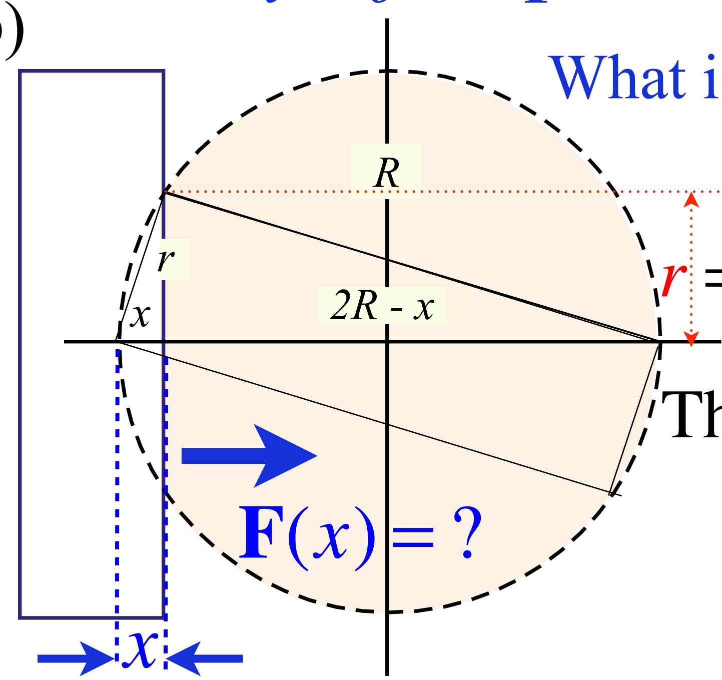
Potential Energy Geometry of Superballs and Related things

(a)



Unit 1
Fig. 7.1
(modified)

(b)



What is superball bounce force law $\mathbf{F}(x)$?

$$r = \sqrt{x(2R - x)} \quad \left(\approx \sqrt{2Rx} \quad \text{for: } \; x << R\right)$$

Thales' geometry and "Sagittal†" approx.

$$\frac{x}{r} = \frac{r}{2R - x}$$

† "bow"

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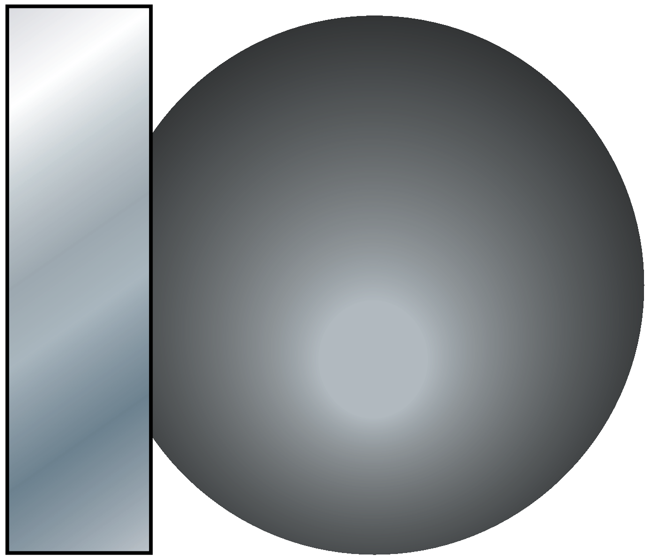

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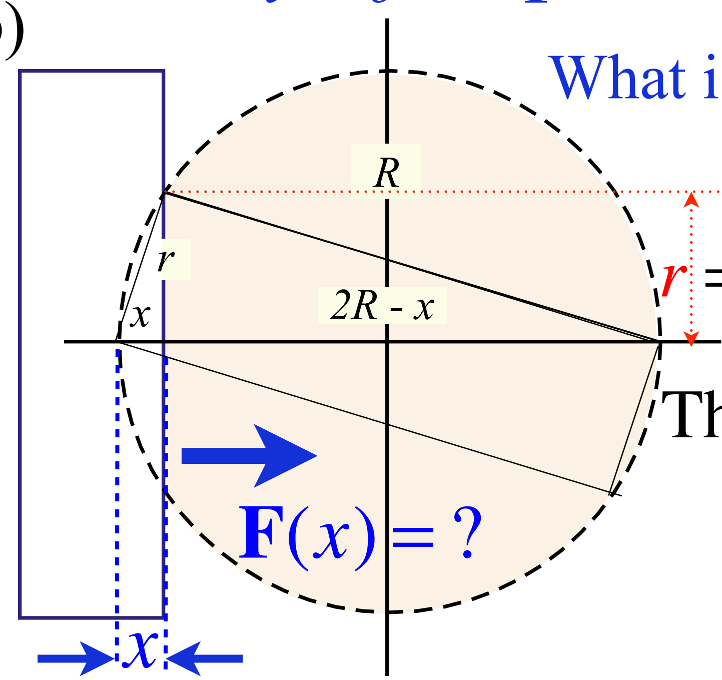

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If superball was a balloon its bounce force law would be linear $F=-k\cdot x$ *(Hooke Law)*

(Pressure)·(Area)

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

$$\approx P\cdot\pi 2Rx$$

Potential Energy Geometry of Superballs and Related things

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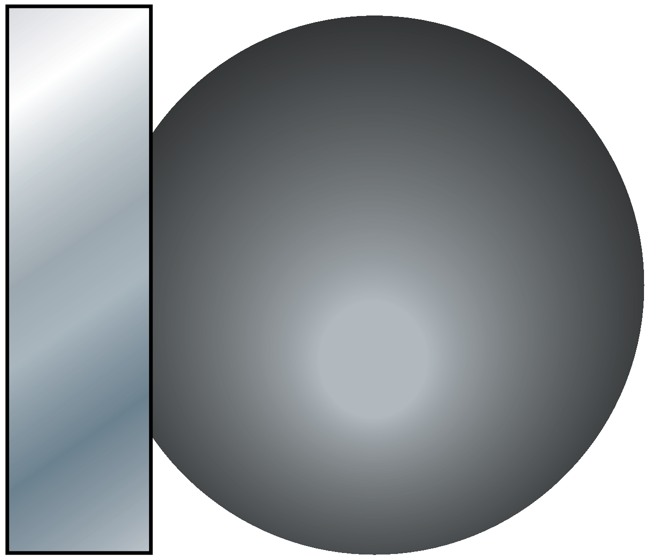

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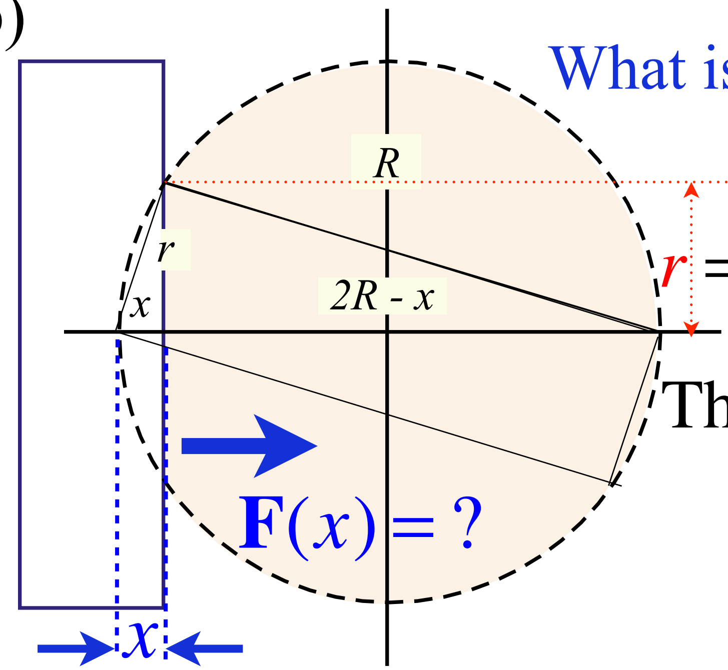

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(Hooke spring constant k)

$$= kx$$

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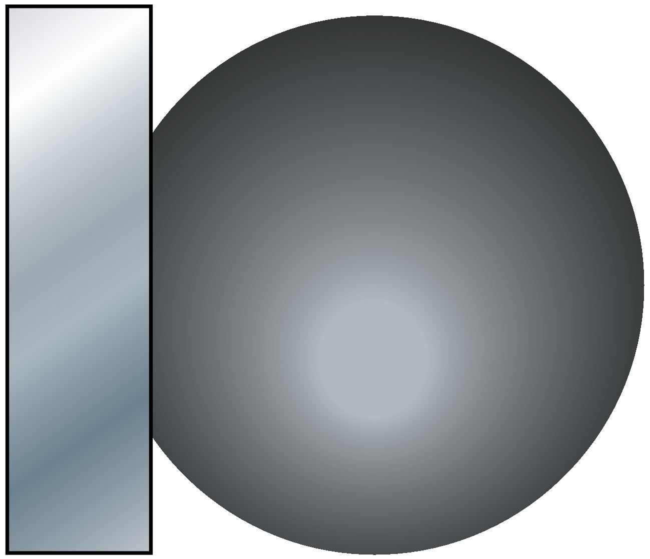

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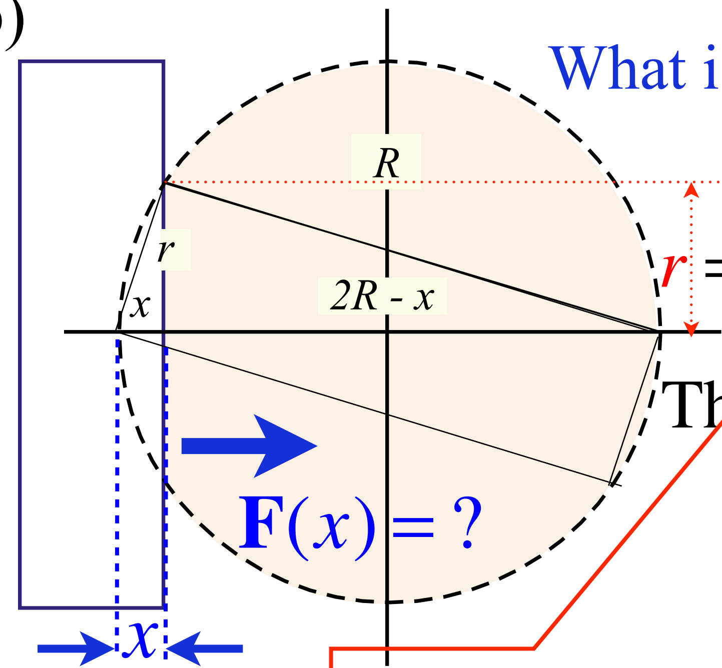

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$$\approx P\cdot \pi 2Rx = P\cdot 2\pi R x$$ *(Hooke spring constant k)*

$$= kx$$

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

$$Volume(X) = \int_0^X \pi r^2\, dx = \int_0^X \pi x(2R-x)\, dx$$

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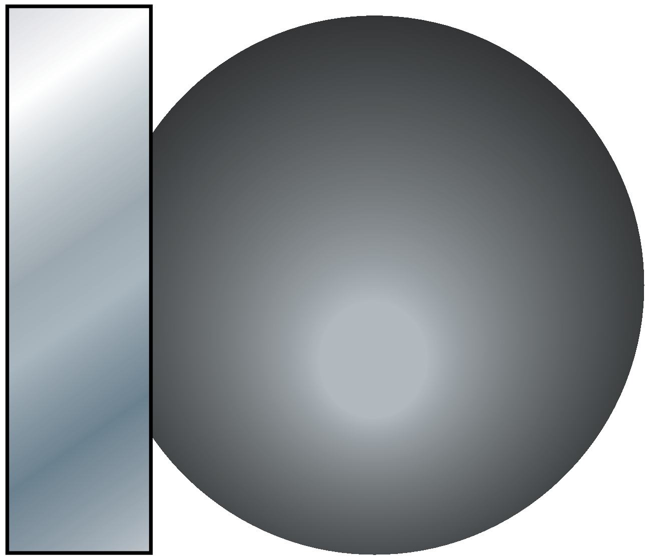

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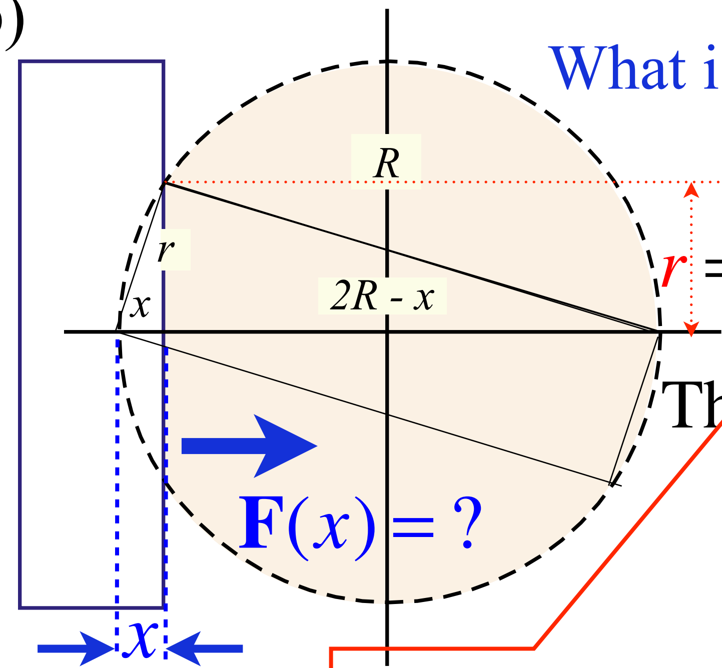

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$$\approx P\cdot\pi 2Rx = \underbrace{P\cdot 2\pi R}_{(Hooke\ spring\ constant\ k)} x$$

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

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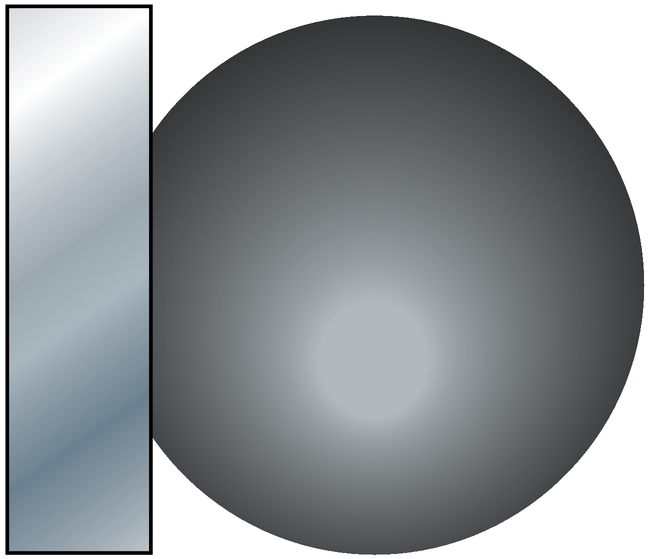

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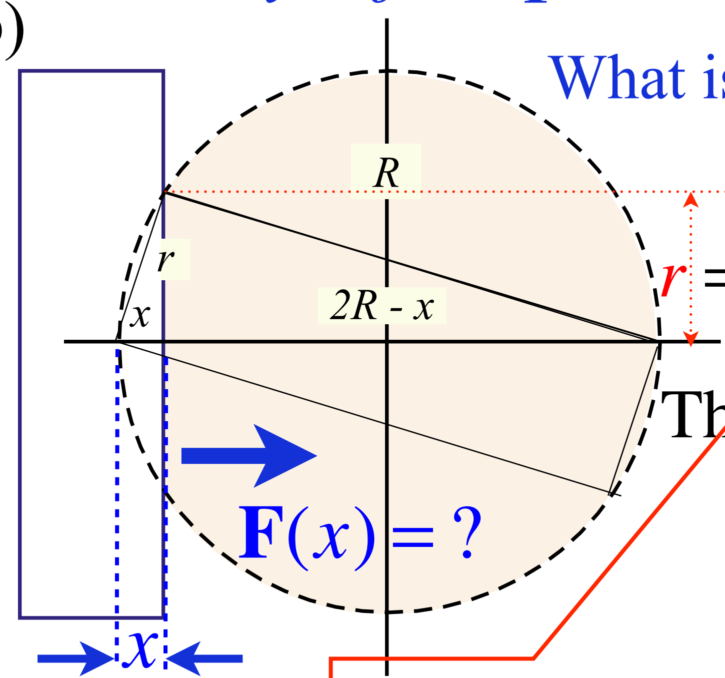

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It also depends on velocity $\dot{x} = \frac{dx}{dt}$. *Adiabatic* differs from *Isothermal* as shown by *"Project-Ball*"*

* *Am. J. Phys.* **39**, 656 (1971)

(Discussed after p. 33)

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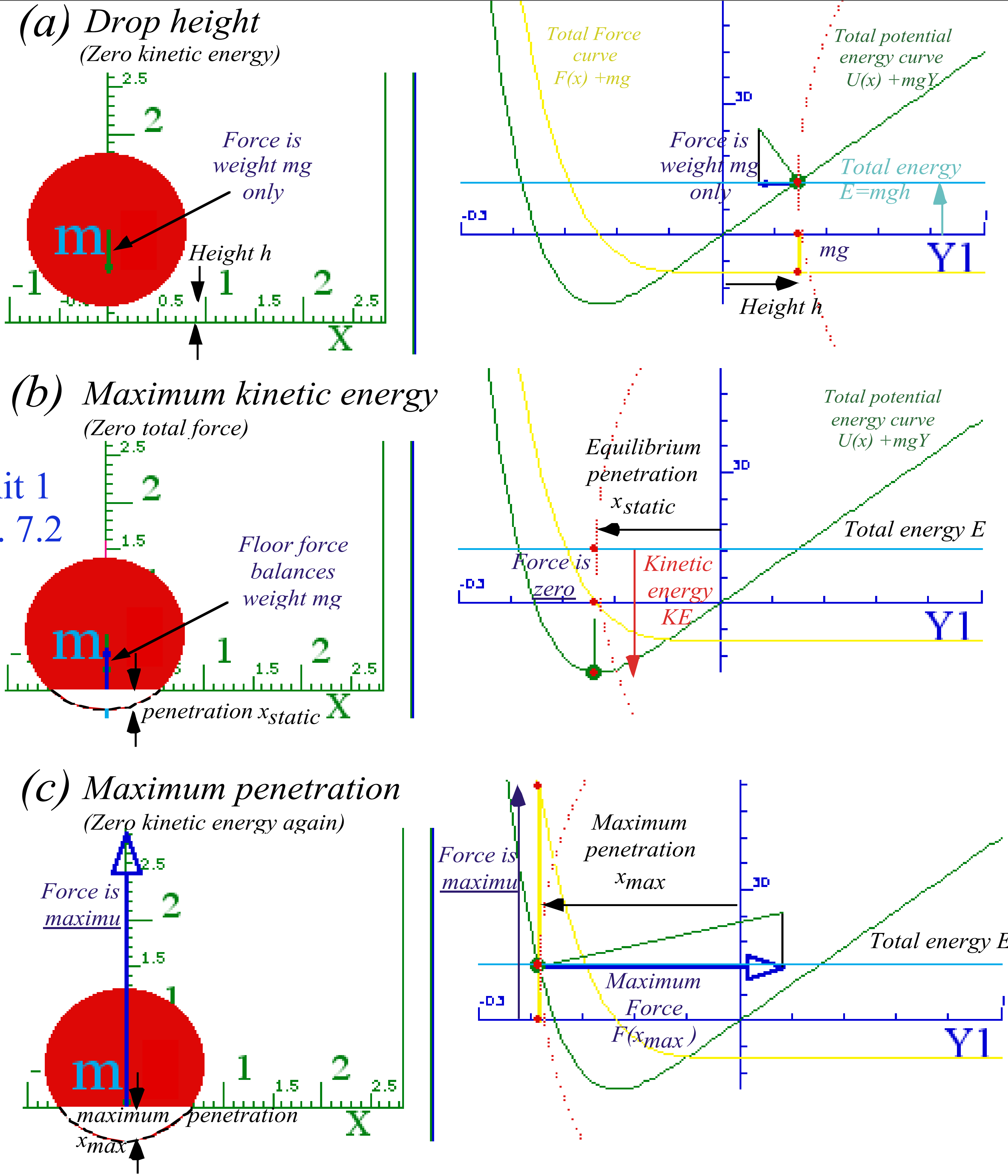
Unit 1
Fig. 7.2



1990 BounceIt Mac simulations

Details of each case follows using newer Web simulations

BounceIt Simulation: Force/Potential Plot

Main Control Panel

Start | Resume

- ◉ Let mouse set: (x,y,Vx,Vy)
- ○ Let mouse set force: F(t)
- ○ Plot solid paths
- ◉ Plot dotted paths
- ○ Plot no paths
- ○ Plot V1 vs. V2
- ○ Plot Y1(t), Y2(t), ...
- ◉ Plot PE of m1 vs. Y1
- ○ Plot Y2 vs. Y1
- ○ Plot user defined i.e - Y1 vs. Y2
- ○ Balls initially falling
- ◉ Balls initially fixed
- ○ No preset initial values

Number of masses: 1 Balls

Acceleration of gravity: 0.5 100x{cm/s^2}

Sets gravity →

- ☑ Draw force vectors
- ☑ Pause (once) at top
- ☑ Constrain motion to Y-axis
- ☑ Plot v2 vs v1
- ☐ Plot p2 vs p1
- ☐ Plot V2 vs V1
- ☐ Plot Ellipses
- ☐ Plot Bisector Lines
- ☐ Old Color Scheme

Collision friction (Viscosity): 0 x10^ 0 {g}

Initial gap between balls: 5.45 x10^ -1 {g}

Force power law exponent: 1

← *This is linear setting (increase for non-linear)*

Force Constant: 500

Canvas Aspect Ratio - W/H i.e. 0.75 & 1.0: 0.75

---

		y Max =	7
Initial x1 =	0.5	y Min =	0
Max x PE plot =	0.5	T Max =	6
F-Vector scale =	0.003	V2y Max =	3
Error step =	0.000	V2y Min =	-2

---

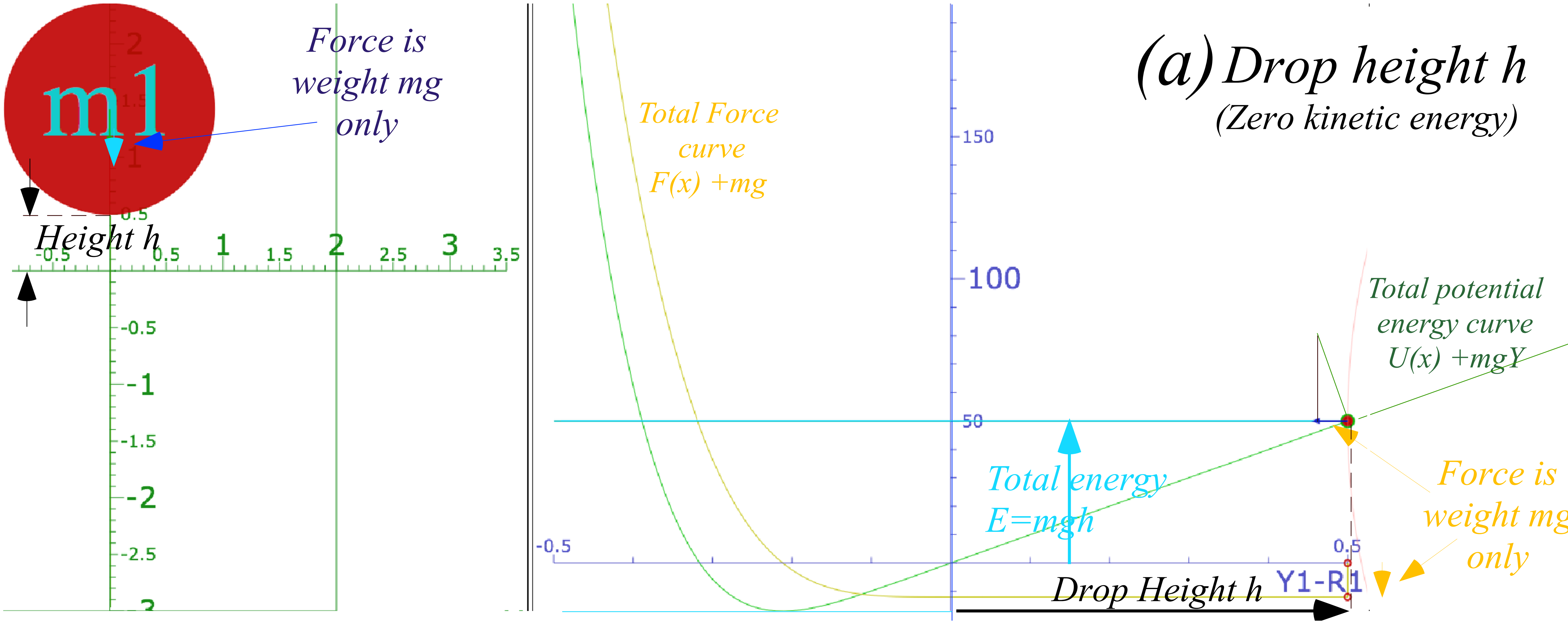
m1= 1 x10^ 2 {g} $V1_0$= 0 x10^ 0 {cm/s}

[BounceIt Simulation: Force/Potential Plot]

Zero Gap 2-Ball Collision (m1:m2 = 1:7)	
Linear 2-Ball Collision (m1:m2 = 1:7)	
Newton's Balls (Zero gap, Nonlinear force)	
Newton's Balls (Zero gap, Linear force)	
3-Ball Tower	5-Ball Towe
→ Potential Plot (1 Ball, Nonlinear force)	
→ Potential Plot (1 Ball, Linear force)	
→ Gravity Potential (1 Ball, Nonlinear force)	
→ Gravity Potential (1 Ball, Linear force)	

(See Simulations)

(a) Drop height h
(Zero kinetic energy)



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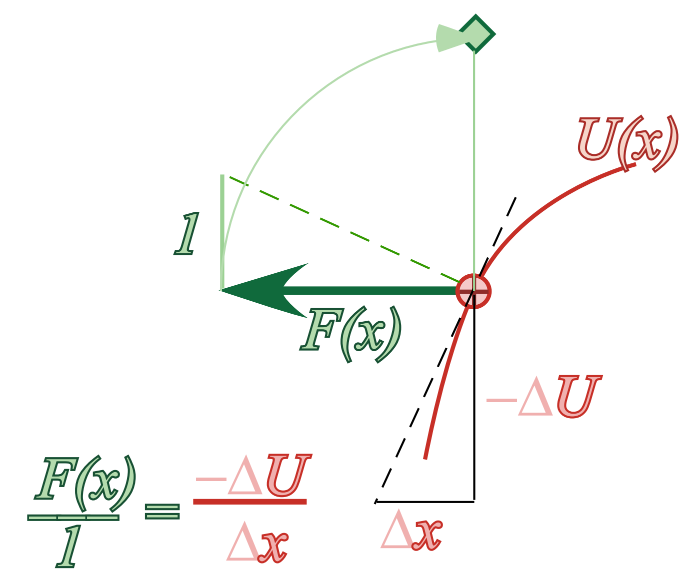
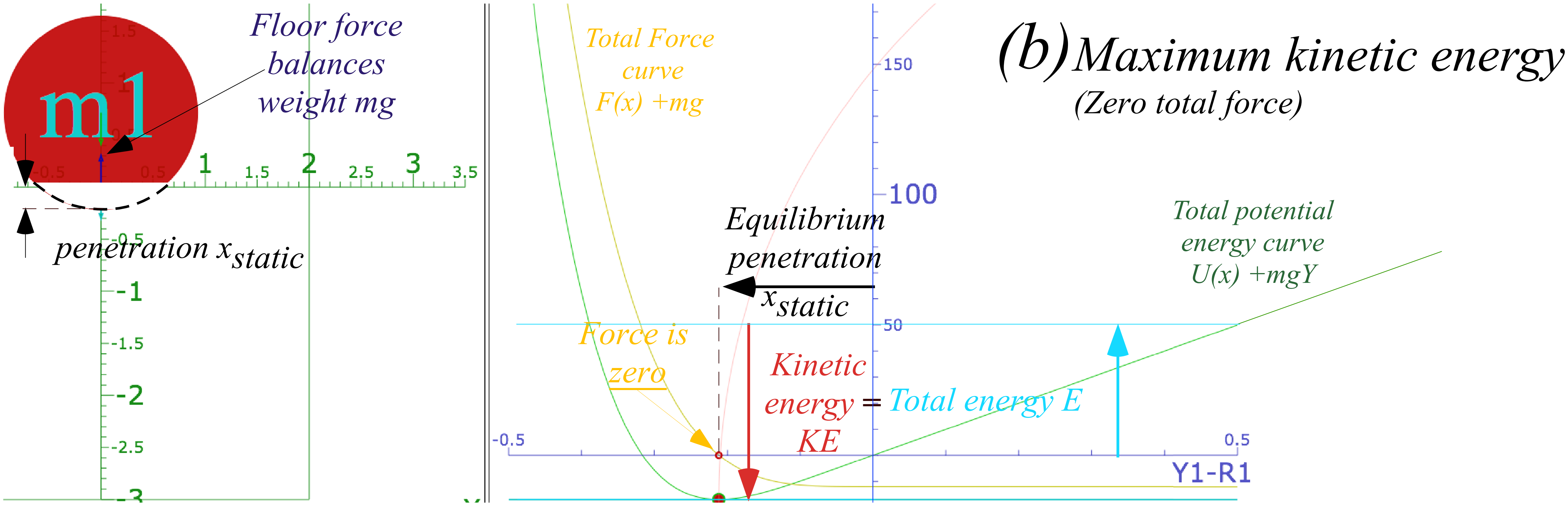
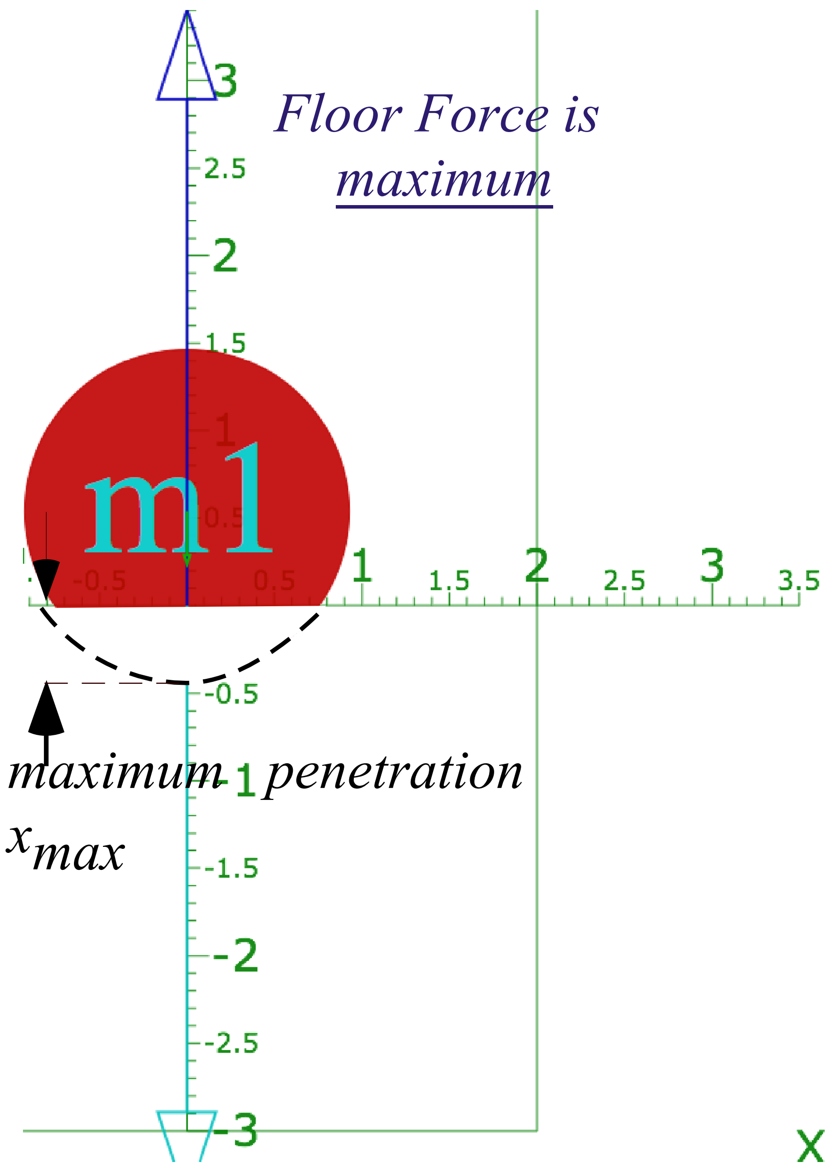


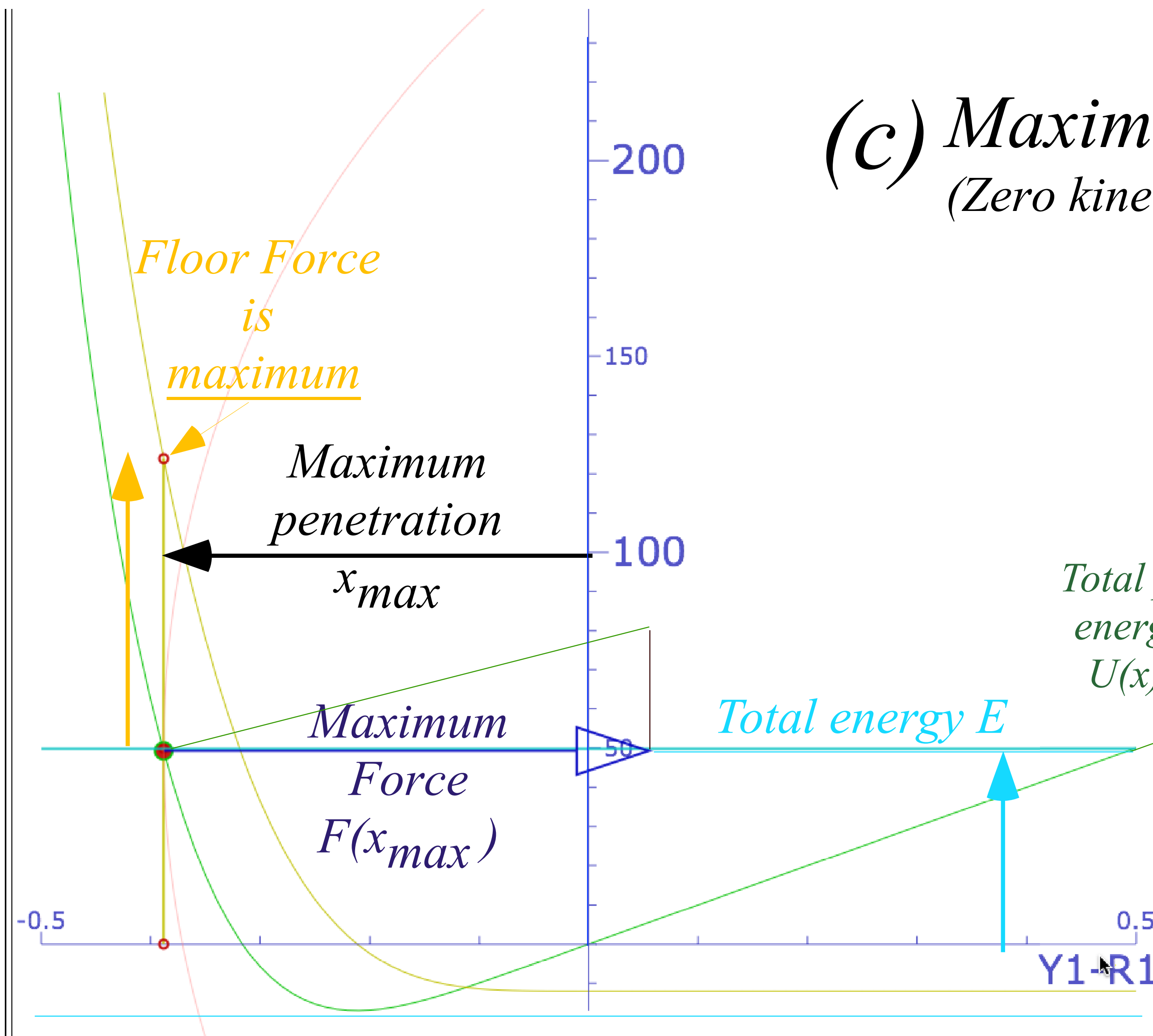
Display of Force vector using similar triangle constuction based on the slope of potential curve.

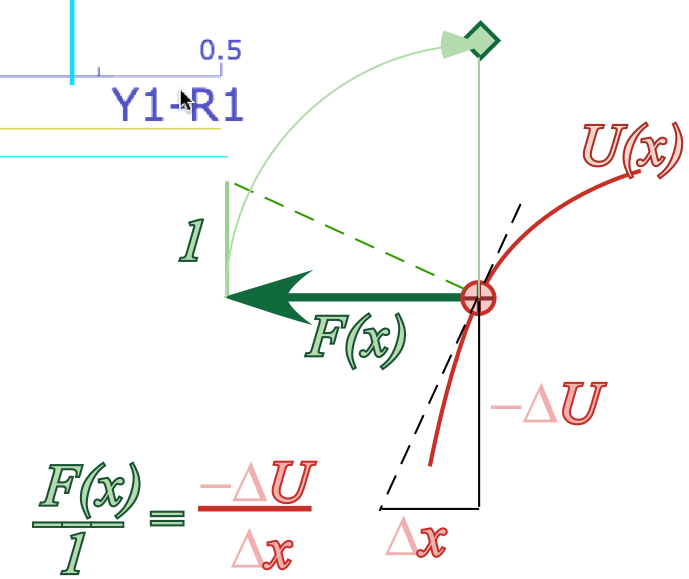

(b) Maximum kinetic energy
(Zero total force)
m1
Floor force
balances
weight mg
penetration x_{static}
Total Force
curve
F(x) +mg
Equilibrium
penetration
x_{static}
Force is
zero
Kinetic
energy
KE
=
Total energy E
Total potential
energy curve
U(x) +mgY
Y1-R1
150
100
50
-0.5
0.5
1
1.5
2
2.5
3
3.5
-1
-1.5
-2
-2.5



(c) Maximum penetration

(Zero kinetic energy again)





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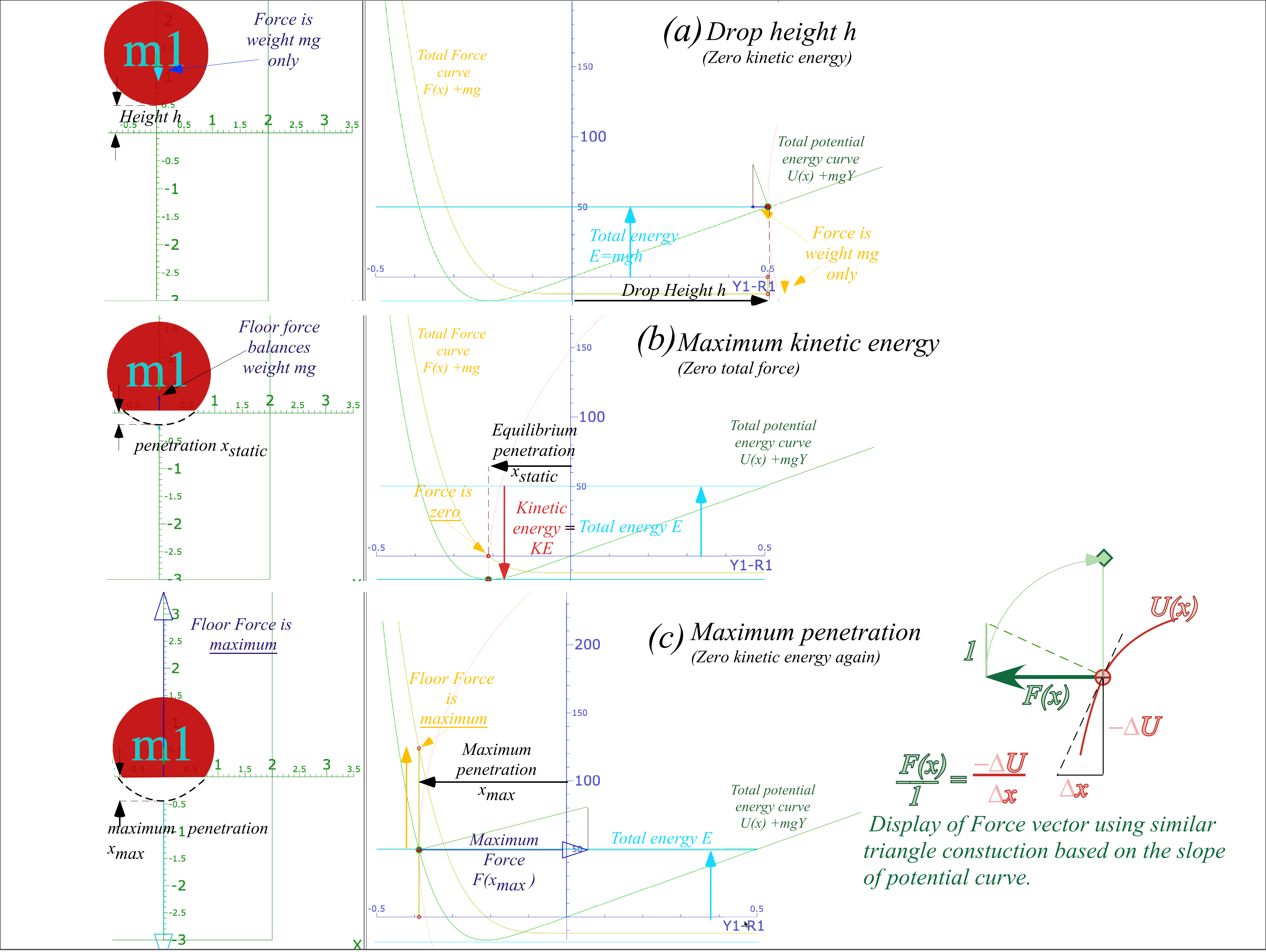
(a) Drop height h
(Zero kinetic energy)
Force is weight mg only
Height h
Total Force curve F(x) +mg
Total potential energy curve U(x) +mgY
Total energy E=mgh
Force is weight mg only
Drop Height h
Y1-R1
(b) Maximum kinetic energy
(Zero total force)
Floor force balances weight mg
penetration x_static
Total Force curve F(x) +mg
Equilibrium penetration x_static
Total potential energy curve U(x) +mgY
Force is zero
Kinetic energy KE = Total energy E
Y1-R1
(c) Maximum penetration
(Zero kinetic energy again)
Floor Force is maximum
maximum penetration x_max
Floor Force is maximum
Maximum penetration x_max
Total potential energy curve U(x) +mgY
Maximum Force F(x_max)
Total energy E
Y1-R1
U(x)
1
F(x)
−ΔU
Δx
F(x)/1 = −ΔU/Δx
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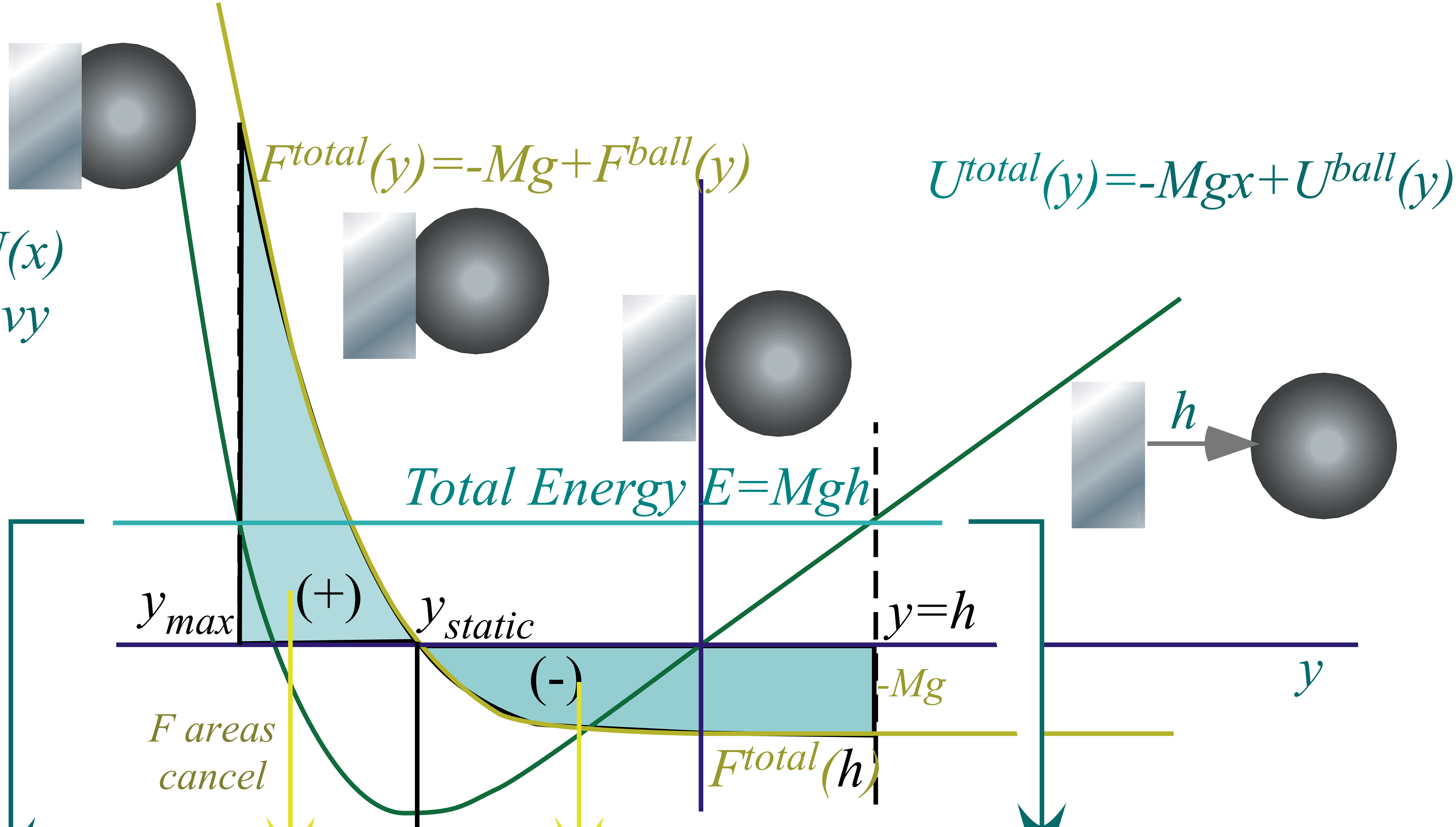
Force F(x) and Potential U(x) for soft heavy non-linear superball



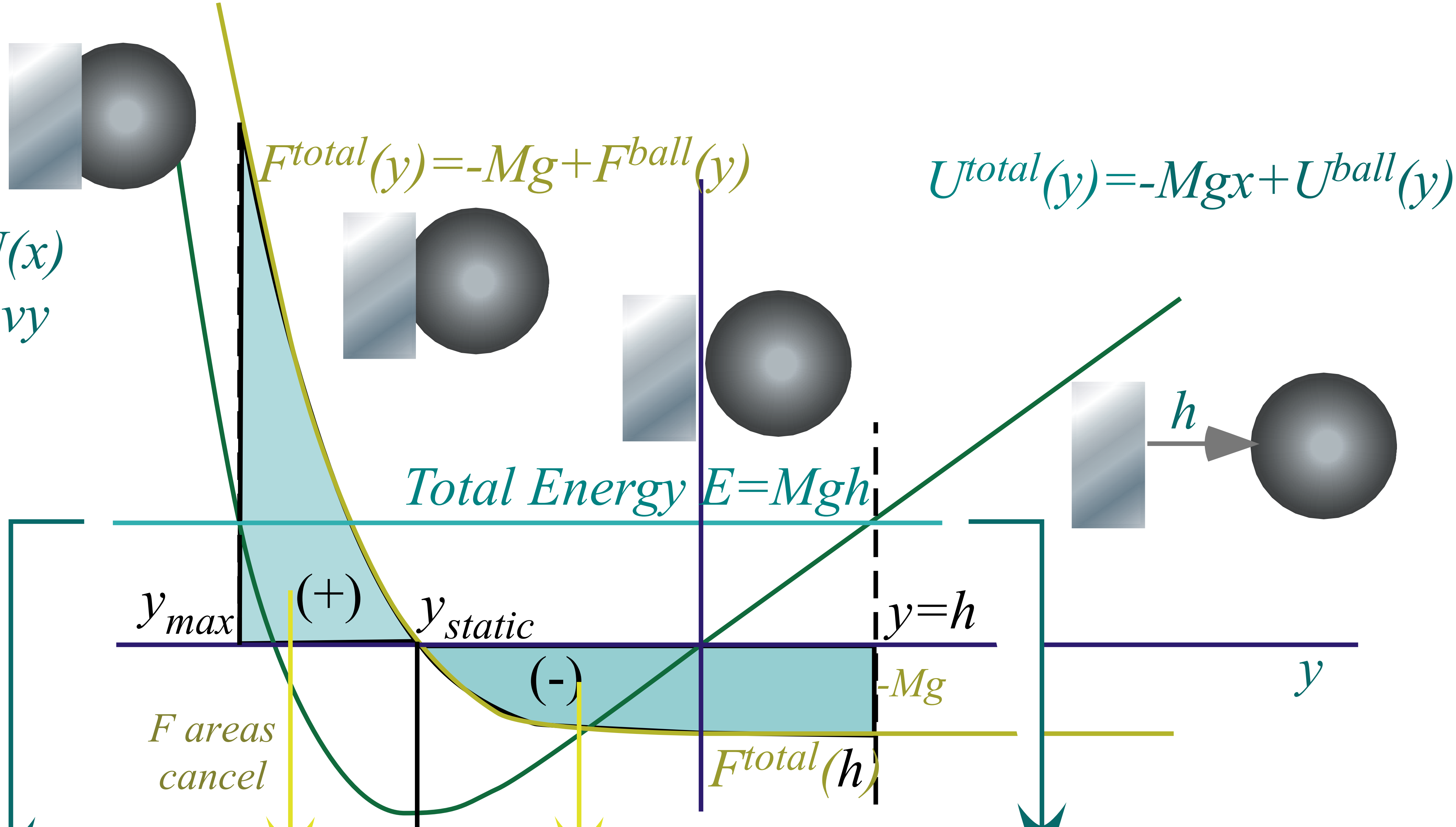
Unit 1
Fig. 7.5

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

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

Force F(x) and Potential U(x) for soft heavy non-linear superball

Unit 1
Fig. 7.5



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

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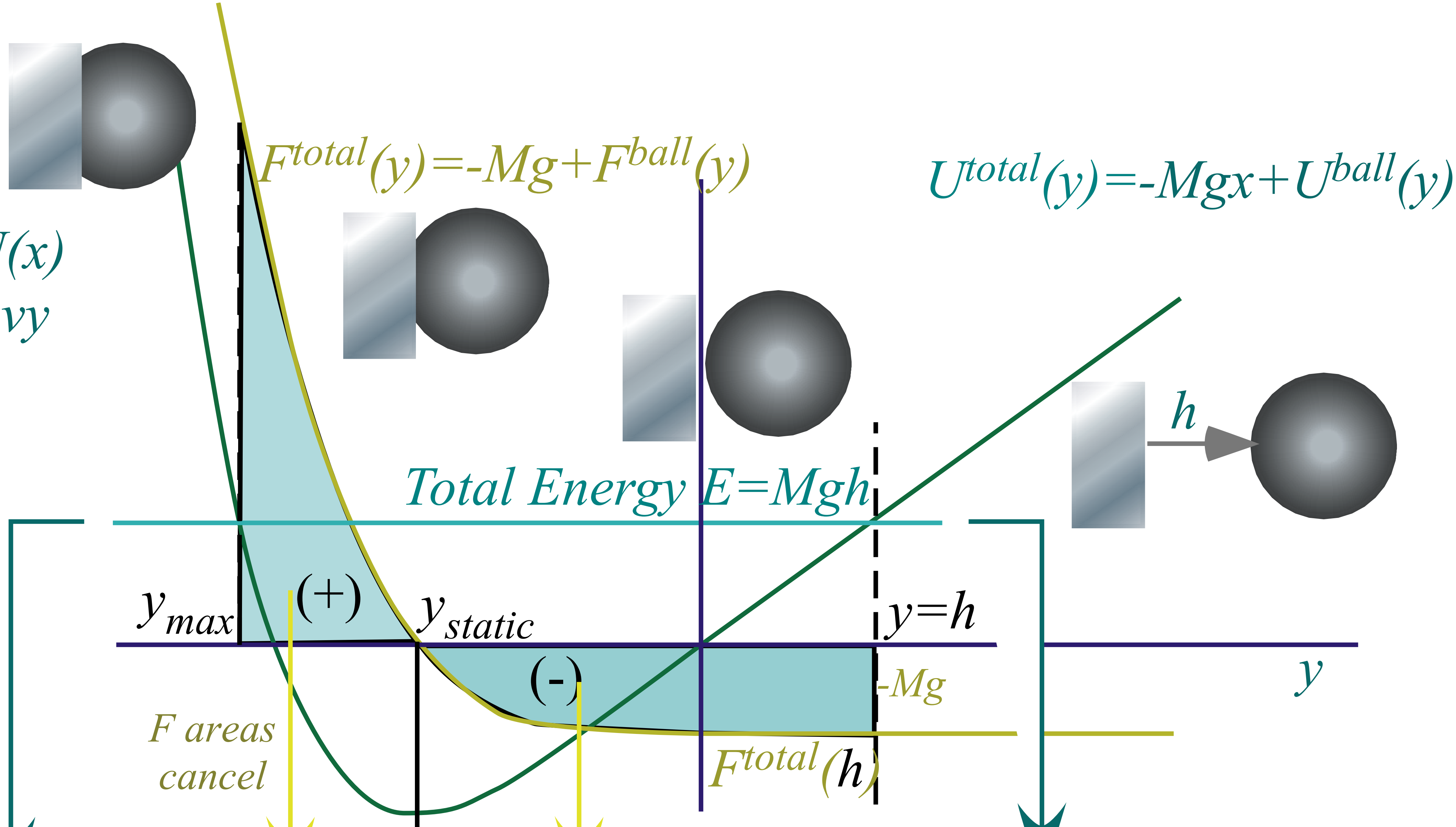

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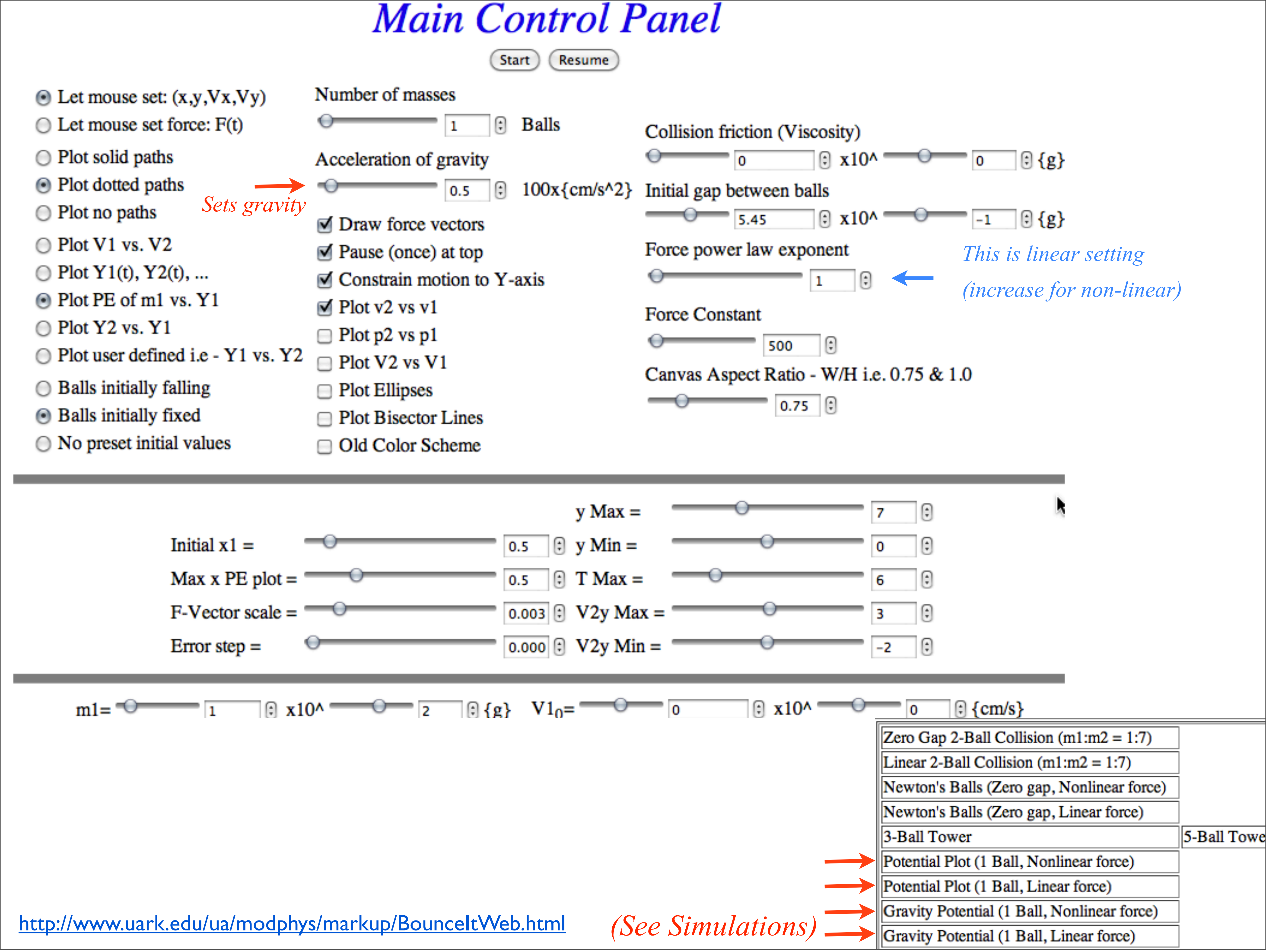
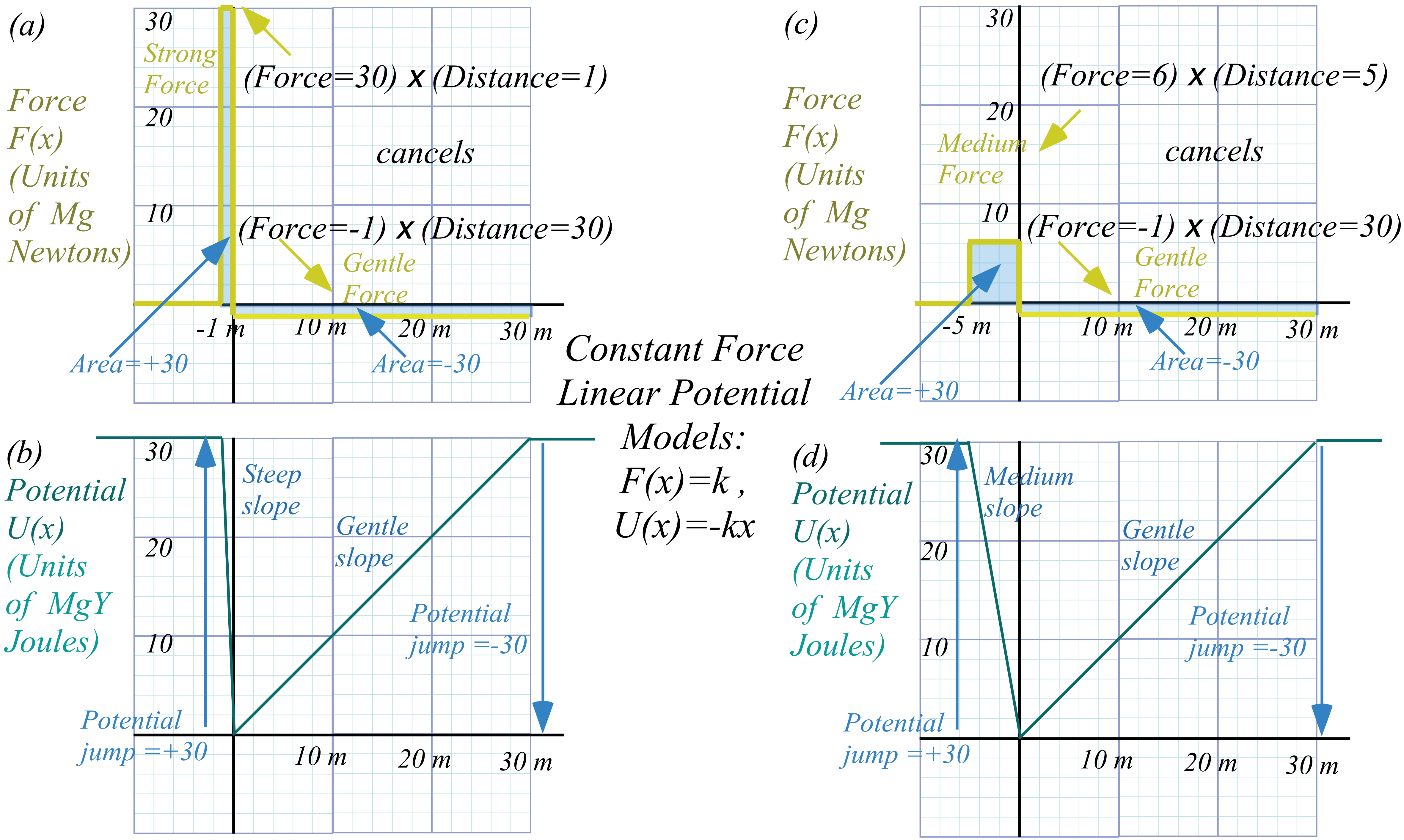


http://www.uark.edu/ua/modphys/markup/BounceItWeb.html

(See Simulations)



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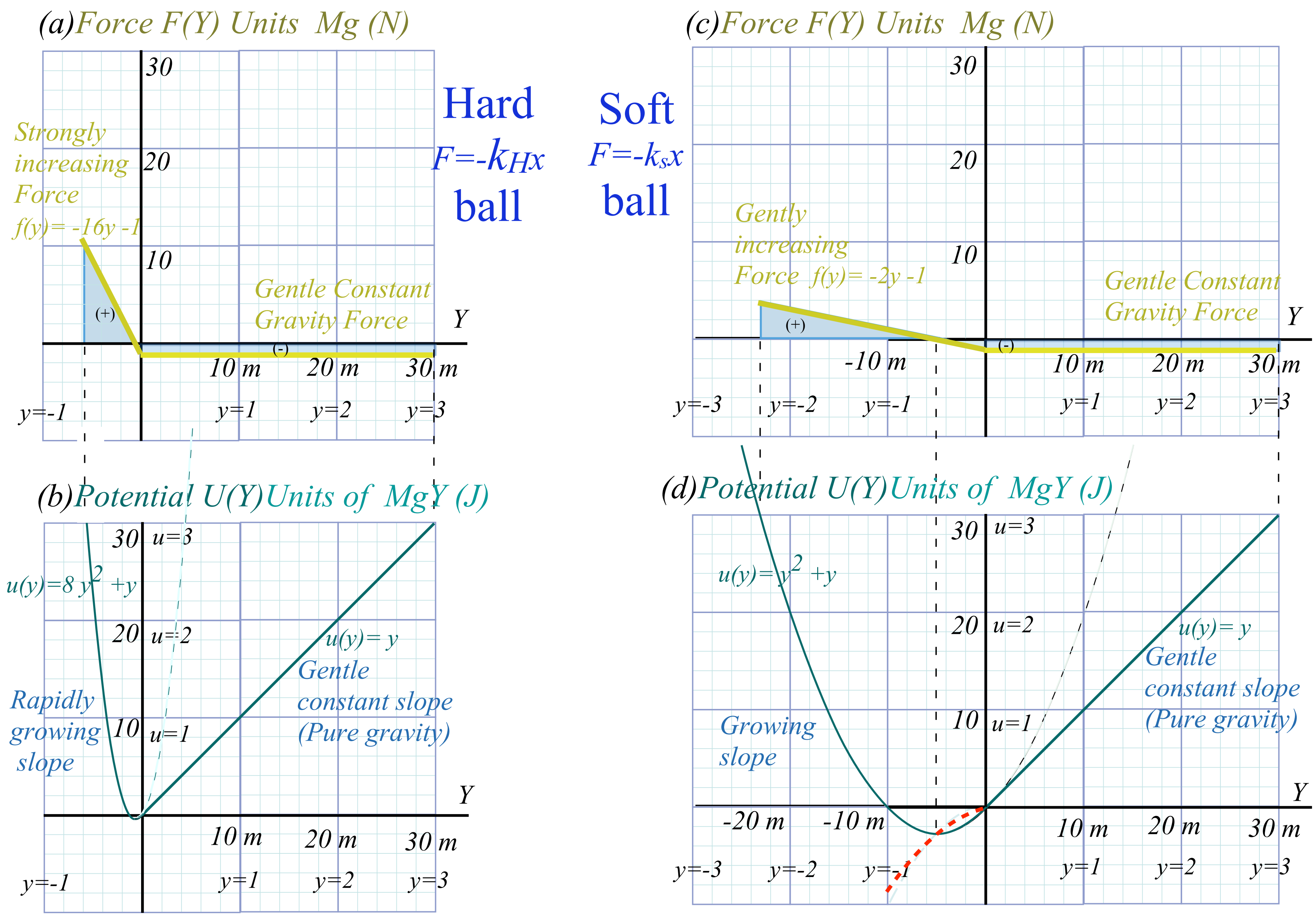
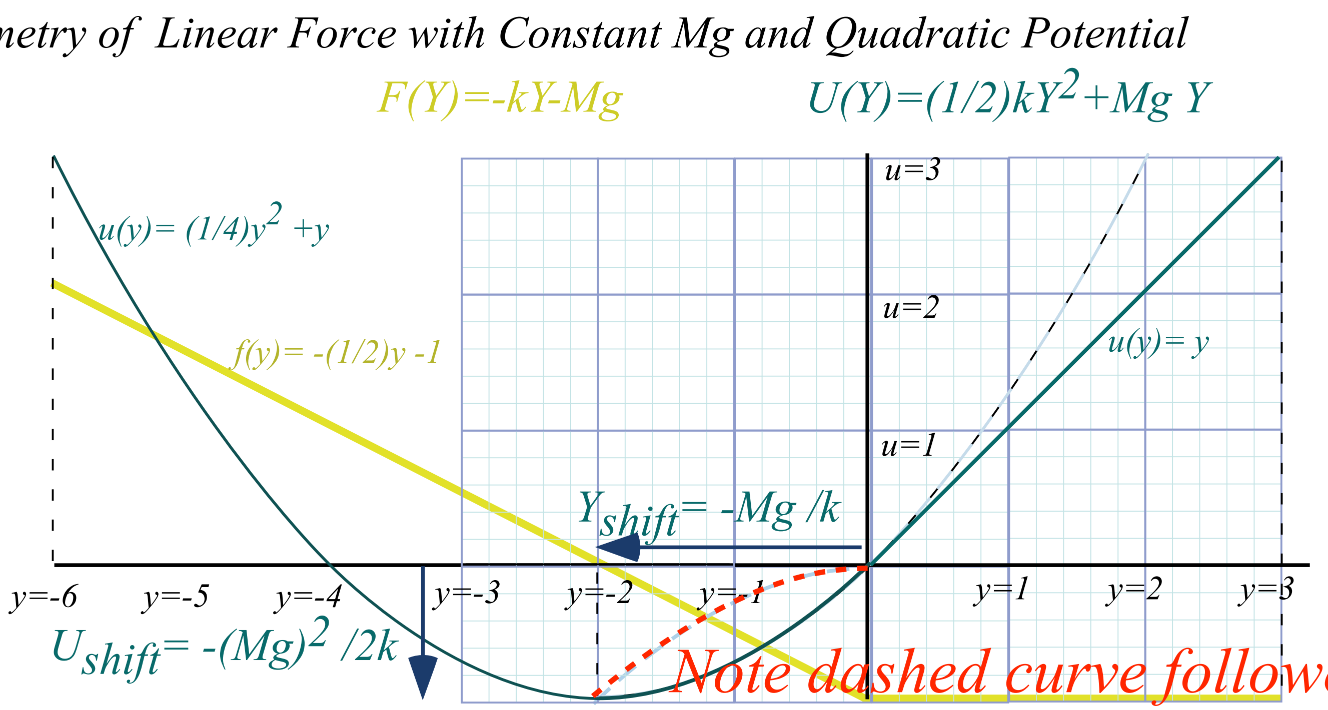


Unit 1
Fig. 7.4

Close view of Soft $F=-k_s x$ ball



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

$$U^{Total} = U^{grav} + U^{target} = \begin{cases} Mg\ y & (y \geq 0) \\ Mg\ y + \frac{1}{2}ky^2 & (y < 0) \end{cases}$$

Note dashed curve followed by PE minimum. Parabola? What?

Potential energy dynamics of Superballs and related things

Thales geometry and "Sagittal approximation" to force law

Geometry and dynamics of single ball bounce

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

Constant force F=-k (linear potential V=kx) *(Simulations)*

Some physics of dare-devil-diving 80 ft. into kidee pool

→ *Linear force F=-kx (quadratic potential $V=\frac{1}{2}kx^2$ (like balloon))*

Geometry and potential dynamics of 2-ball bounce

A parable of RumpCo. vs CrapCorp. (introducing 3-mass potential-driven dynamics)

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

Geometry and dynamics of n-ball bounces

Analogy with shockwave and acoustical horn amplifier

Advantages of a geometric m_1, m_2, m_3,... series

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

Many-body 1D collisions

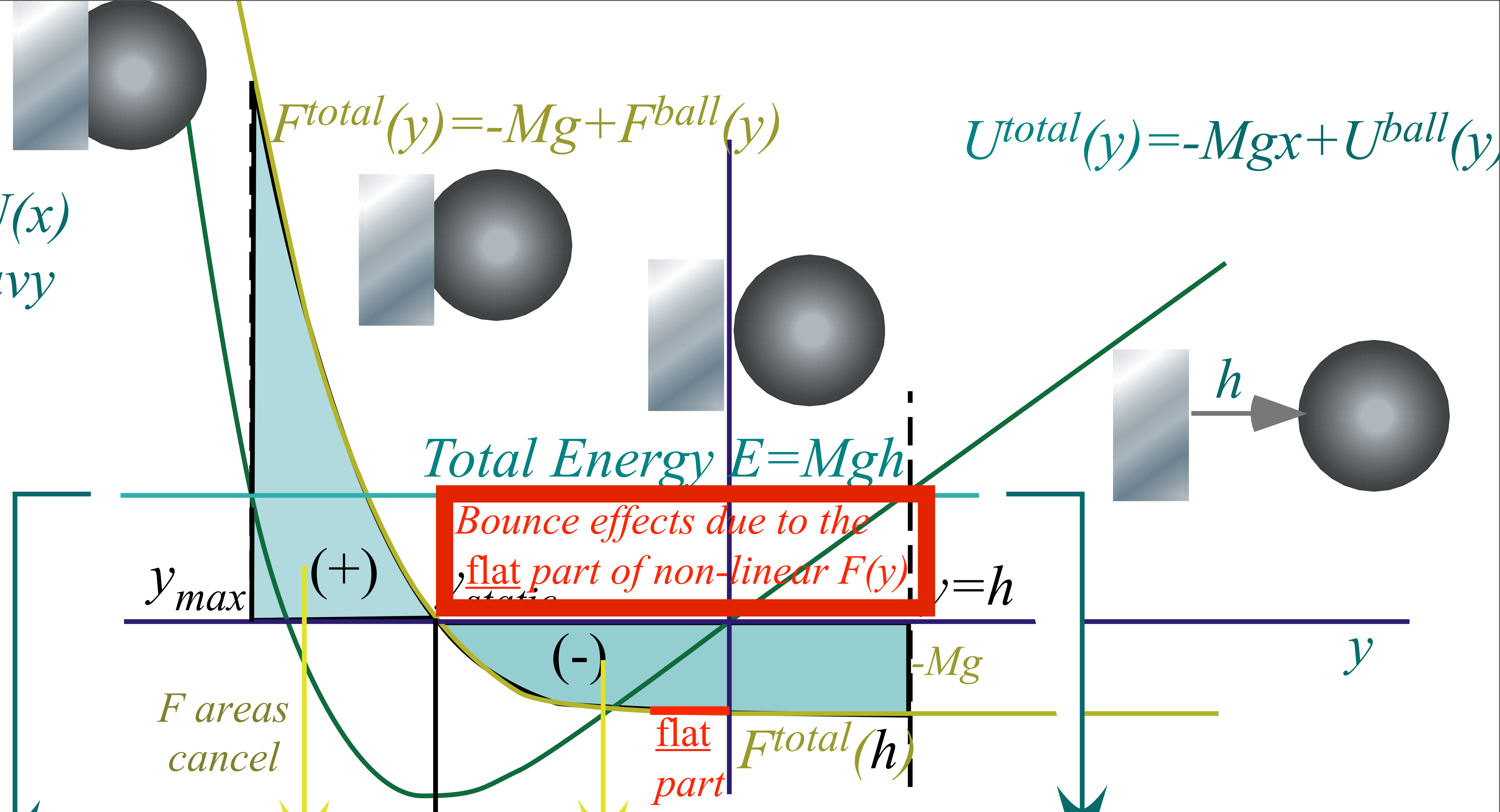
Elastic examples: Western buckboard

Bouncing columns and Newton's cradle

Inelastic examples: "Zig-zag geometry" of freeway crashes

*Super-elastic examples: This really **is** "Rocket-Science"*

Force F(x) and Potential U(x) for soft heavy non-linear superball



Unit 1
Fig. 7.5

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

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

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

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Parable allegory for Los Alamos
Cheap&practical "seat-of-the pants" approach

Parable allegory for Livermore
Fancy&overpriced "political" approach

Advantages of a geometric m_1, m_2, m_3, ... series

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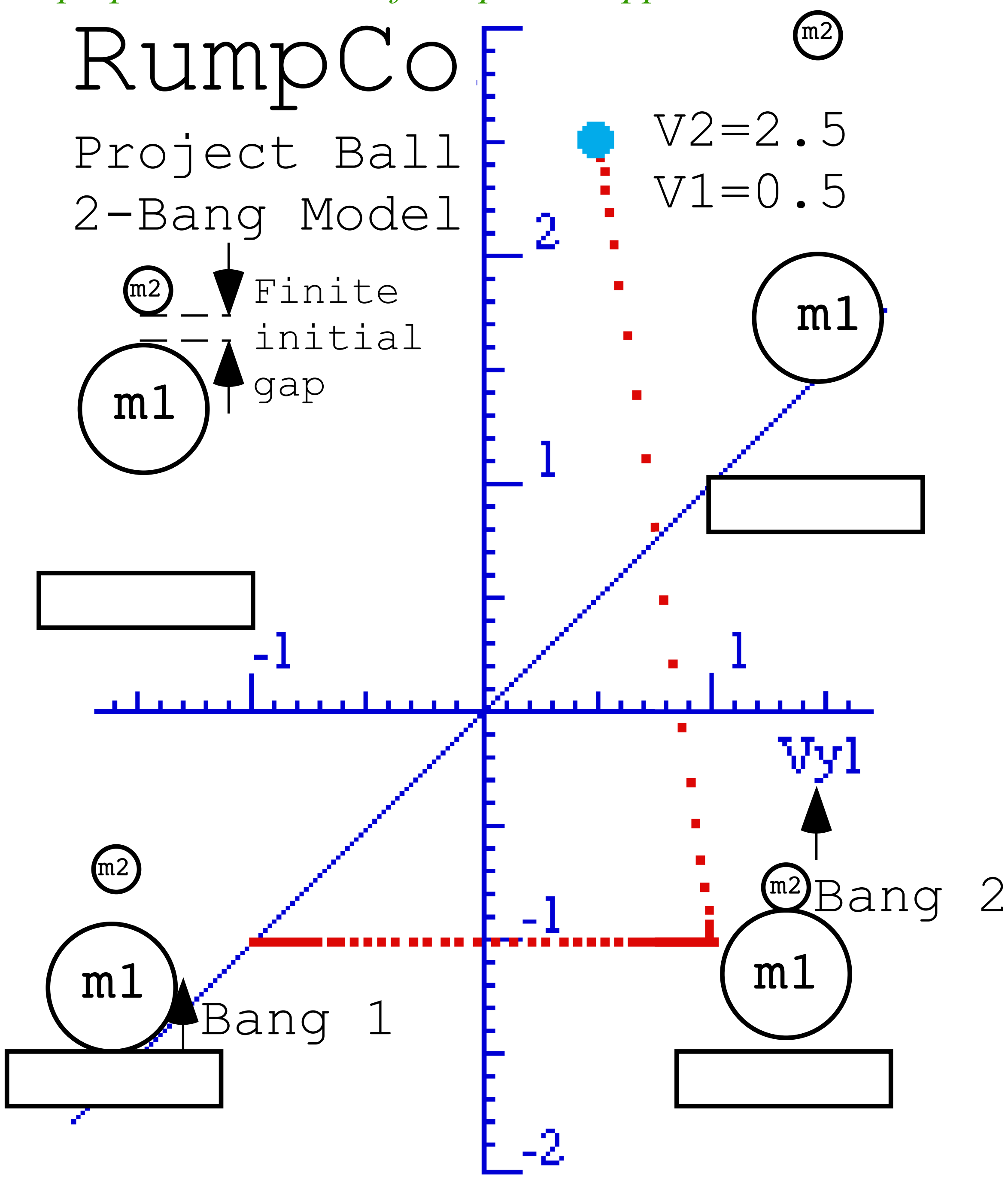
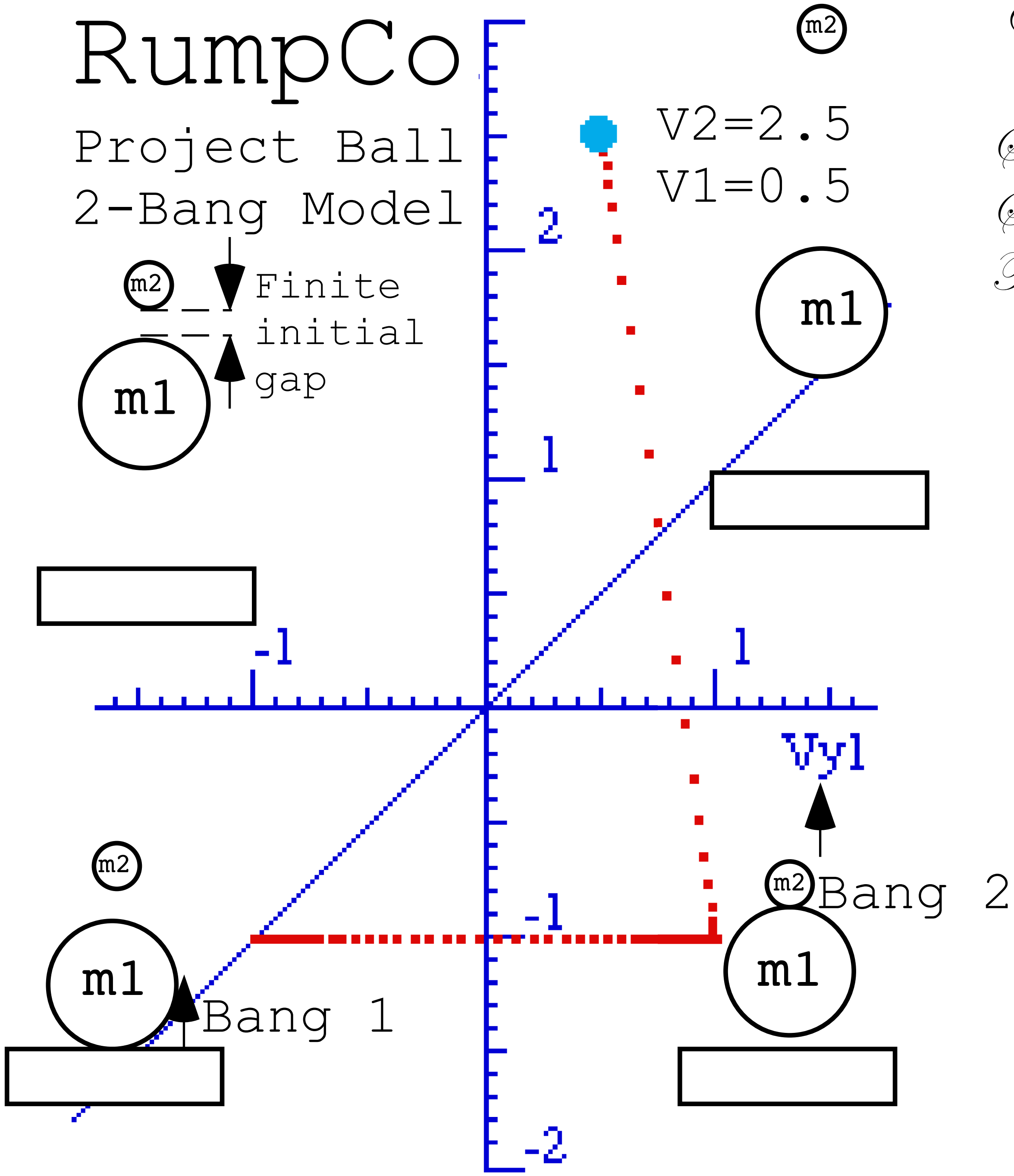


Velocity amplification
or "throw" factor =2.5

Unit 1
Fig. 7.6

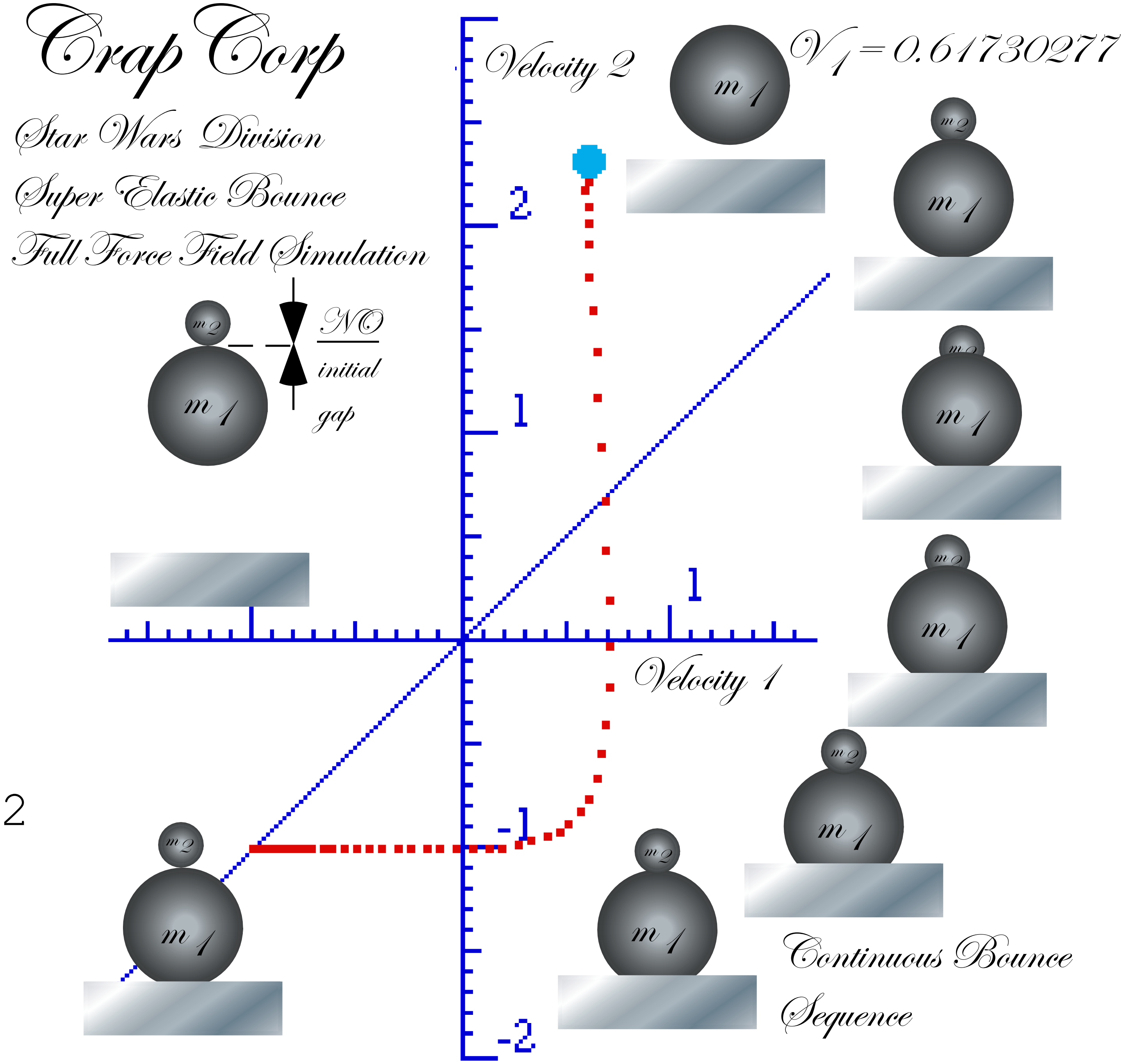
Parable allegory for Los Alamos

Cheap&practical "seat-of-the pants" approach



Parable allegory for Livermore

Fancy&overpriced "political" approach

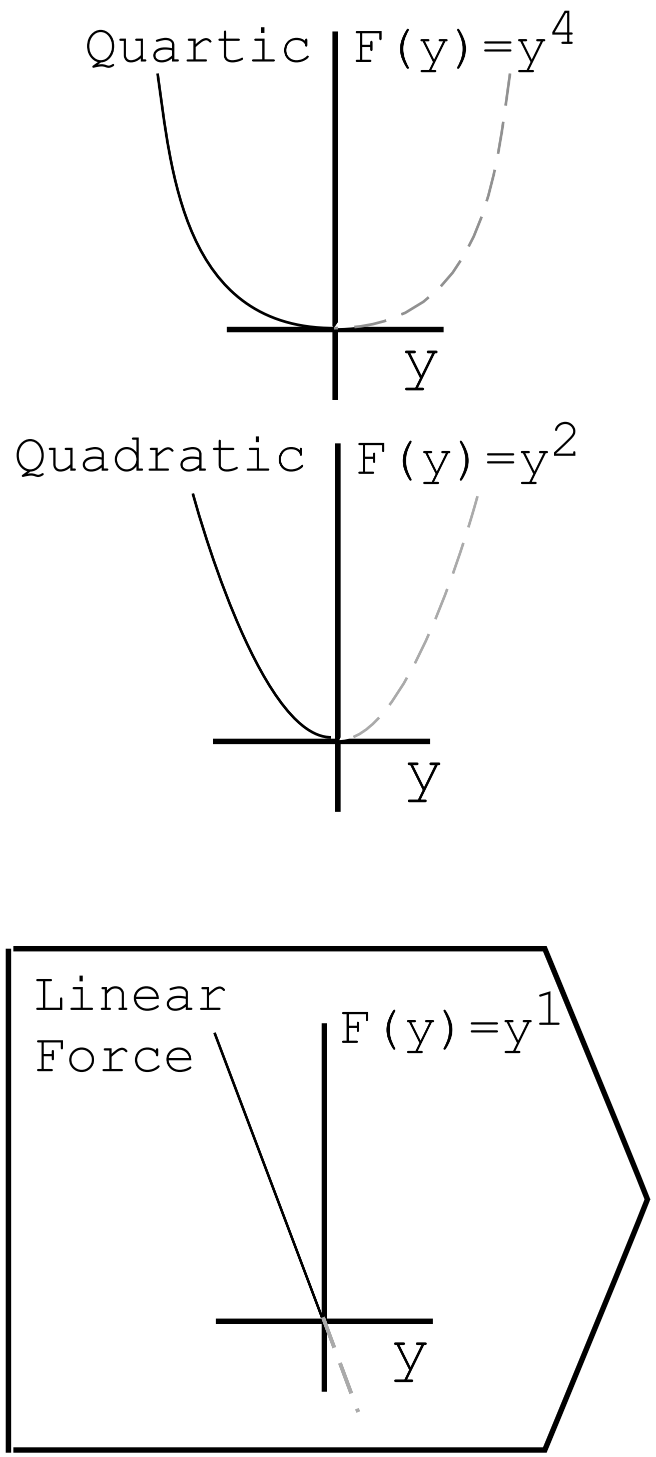


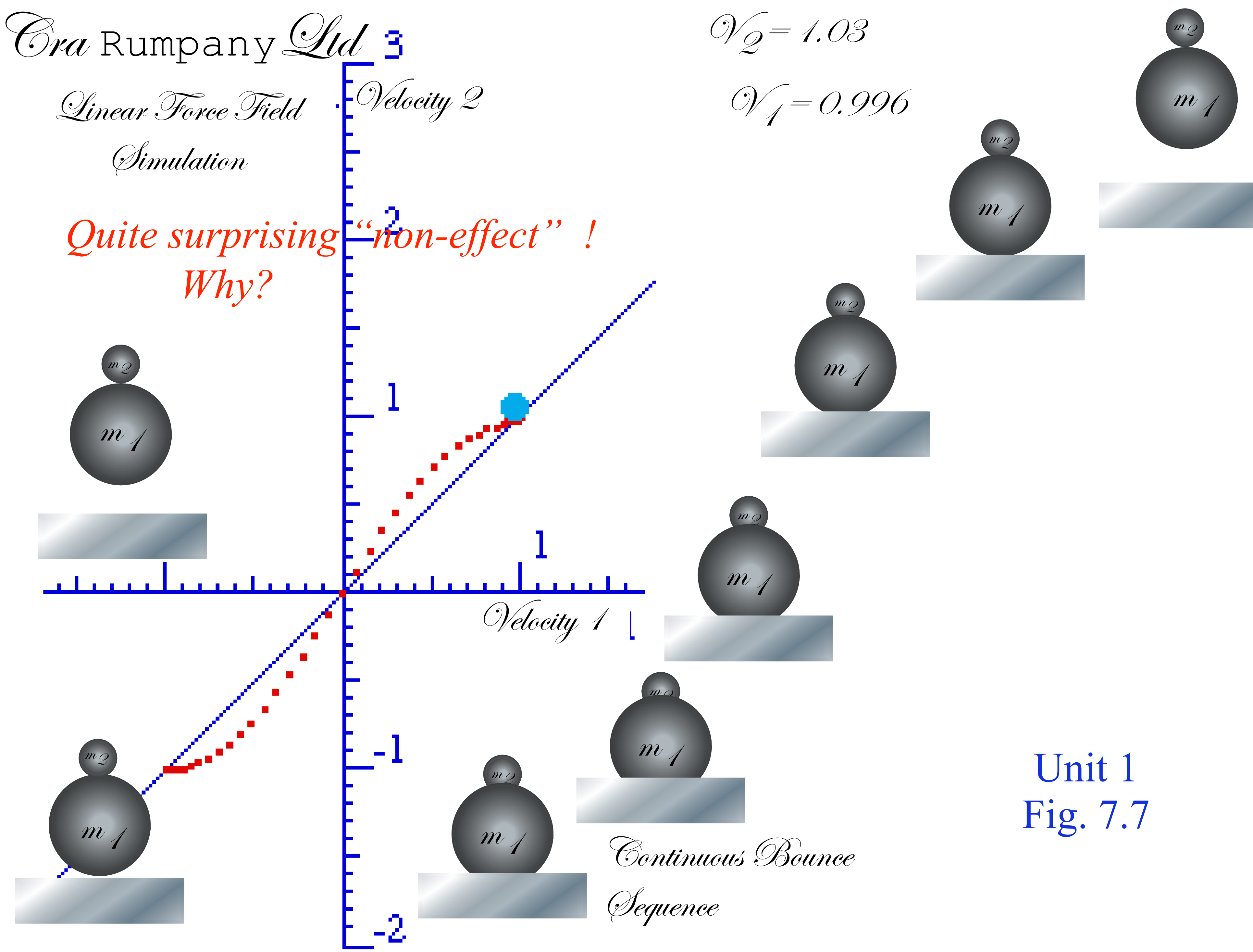
Velocity amplification
or "throw" factor =2.5

Velocity amplification
or "throw" factor =2.3
(about equal to RumpCo
finite gap experiment)

Unit 1
Fig. 7.6

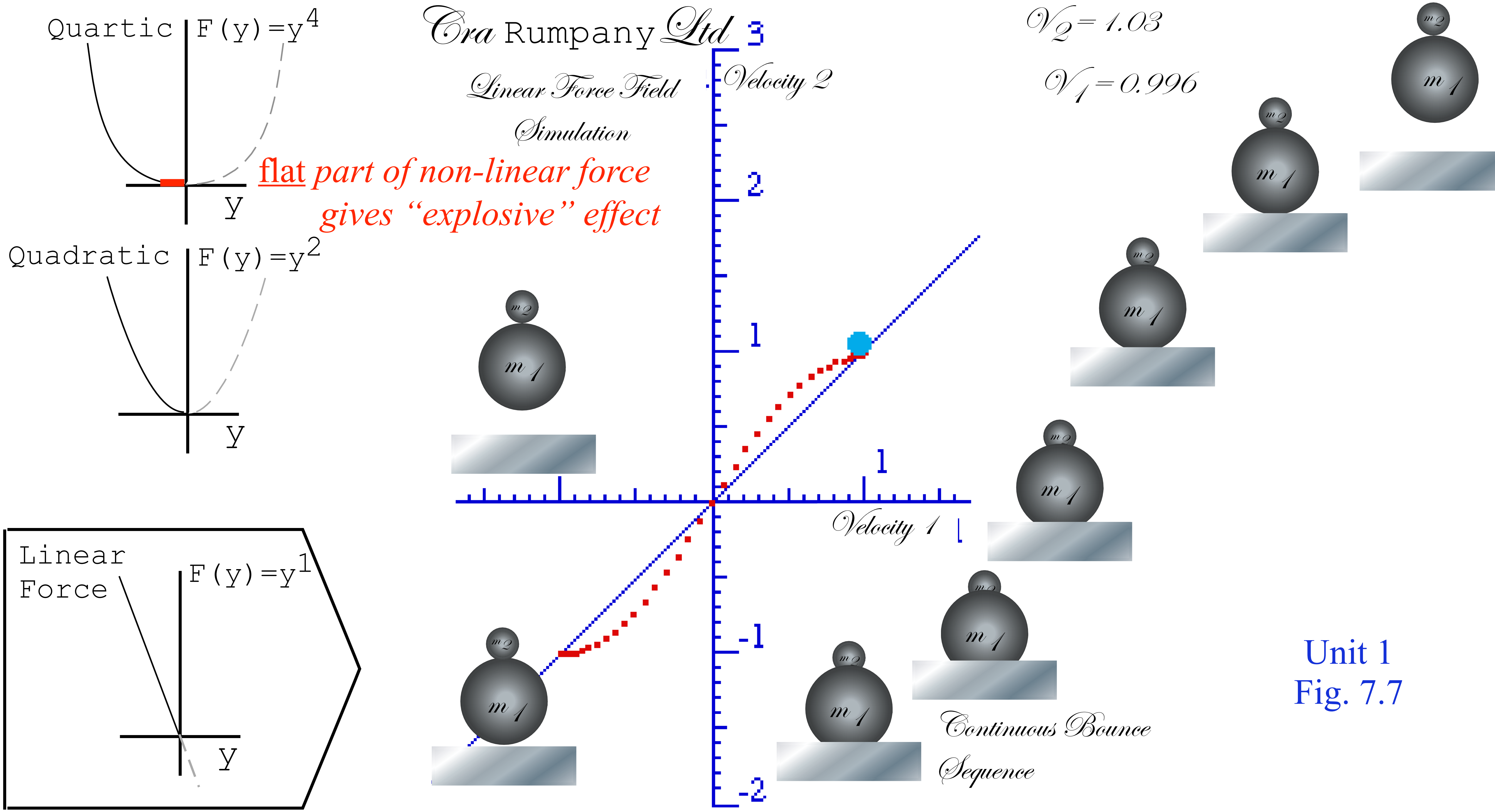
Cooperation between Los Alamos and Livermore yields insight to answer "What's going on?"





Unit 1
Fig. 7.7

Cooperation between Los Alamos and Livermore yields insight to answer "What's going on?"



Velocity amplification
or "throw" factor =1.03
(practically "no-throw")
for linear force F(y)= ky

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Geometry and dynamics of single ball bounce

(a) Constant force F=-k (linear potential V=kx)

Some physics of dare-devil-diving 80 ft. into kidee pool *(Simulations)*

(b) Linear force F=-kx (quadratic potential $V=\frac{1}{2}kx^2$ (like balloon))

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

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→ *A story of USC pre-meds visiting Whammo Manufacturing Co.* *(Leads to Sagittal potential analysis of 2, 3, and 4 body towers)*

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656 / June 1971

Velocity Amplification in Collision Experiments Involving Superballs

...and some results of "Project-Ball"

CLASS OF WILLIAM G. HARTER*
University of Southern California
Los Angeles, California 90007

(Received 25 September 1969; revised 25 September 1970)

If a pen is stuck in a hard rubber ball and dropped from a certain height, the pen may bounce to several times that height. The results of two such experiments, which can easily be duplicated in any undergraduate physics laboratory, are plotted for a range of mass ratios. A simple theoretical discussion which provides a qualitative understanding of the phenomenon is presented. A more complicated formulation which agrees very well with one of the experiments is also presented. The latter involves a simple analog computer program. Finally, an intriguing generalization of the phenomenon is considered.

* The members of the class of Dr. William G. Harter included: Calvin W. Gray, Jr., Robert C. Frickman, Brian P. Harney, Steven H. Hendrickson, Scott T. Jacks, David F. Judy, William D. Koltun, Sam C. Kaplan, Morton J. Kern, Edmund H. Kwan, Wayne E. Long, Michael E. Mason, William D. Moore, Willard W. Mosier, Gary P. Rudolf, Henry G. Rosenthal, William F. Skinner, Jay L. Stearn, Michael Weinberg, Mark Weiner, Frank J. Wilkinson, and David Willner.

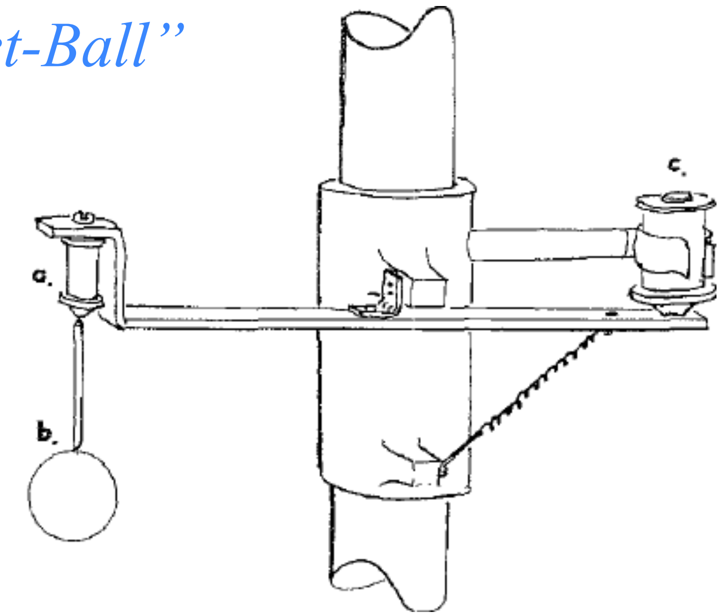
ACKNOWLEDGMENT

We would like to thank John C. Fakan, John E. Heighway, and John H. Marburger for help during the initial and final stages of this project.

INTRODUCTION

Shortly after the well-known Superball[1] appeared on the market, one of the authors quite accidentally discovered a surprising effect.[2] The point of a ball point pen is imbedded in the surface of a 3-in. diam Superball, and the pen and ball are dropped from a height of 4 or 5 ft so that the pen remains above the ball and perpendicular to a hard floor below. As the ball strikes the floor, the pen may be ejected so violently that it will strike the ceiling of the average room with considerable force. Furthermore, one can adjust the mass of the pen so that the ball remains completely at rest on the floor after ejecting the pen.

[1] Trade name of product by Whammo Manufacturing Co., San Gabriel, Calif.



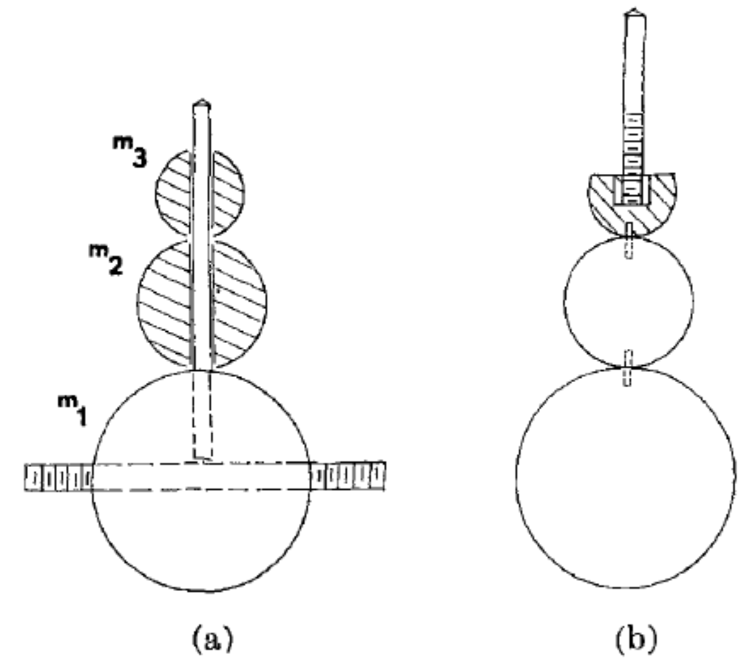


FIG. 14. Two designs for a multiple stage tower of balls. (a) Large number of balls can slide on a shaft. (b) Balls connected by small pins stand to lose appreciable amounts of binding energy.

Much later....
Lots of profs try this out...
...including the unfortunate Harvard professor M. Tinkham...

(Still trying to find the video of the Tinkham incident...)

Basketball and Tennis Ball

Dropping a tennis ball on top of a basketball causes the tennis ball to bounce very high.

Source: 8.01 *Physics I: Classical Mechanics*, Fall 1999
Prof. Walter Lewin

Course Material Related to This Topic:

- Watch video clip from Lecture 17 (21:30 - 24:08)

http://ocw.mit.edu/high-school/physics/exam-prep/systems-of-particles-linear-momentum/impulse-and-momentum/

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

...and some results of "Project-Ball"

After initial big NBC splash (Ray Dunkin Reports) in Fall 1968, USC mechanical engineers kindly measured super-ball force curves F(y) with their precision tensometer and let us use their analog computer to calculate precise bounce heights.

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Seeing us looking sad he offers us boxes of super-balls of many sizes (and other shapes).

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Still a little sad, we return to Rm 69.
Somebody drops a box of balls that immediately bounce into the wet paint.

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The rest is history.
Little paint spots on floor show what was wrong with our fancy-pants computer theory

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...and some results of "Project-Ball"

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Little paint spots on floor show what was wrong with our fancy-pants computer theory.

The engineering curves were <u>isothermal</u> not <u>adiabatic</u>.
Need latter. Can do latter by dropping dyed balls and measuring spot-size.

Measuring spot-size d gives energy vs. height.
Slope of E(x) gives force F(x) and G(x).

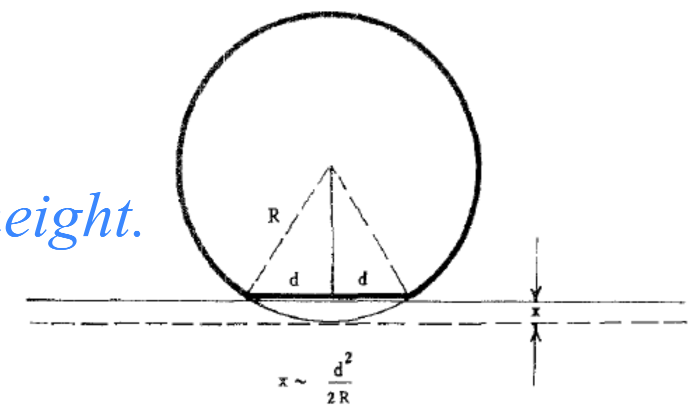
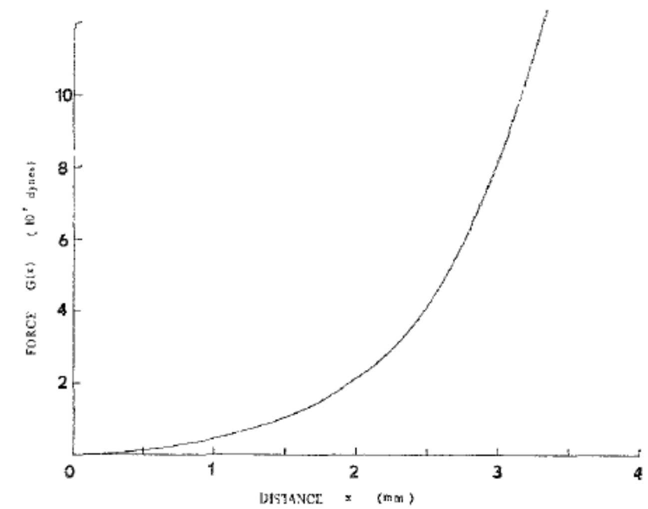


FIG. 10. Sagittal formula.

Collisions Involving Superballs



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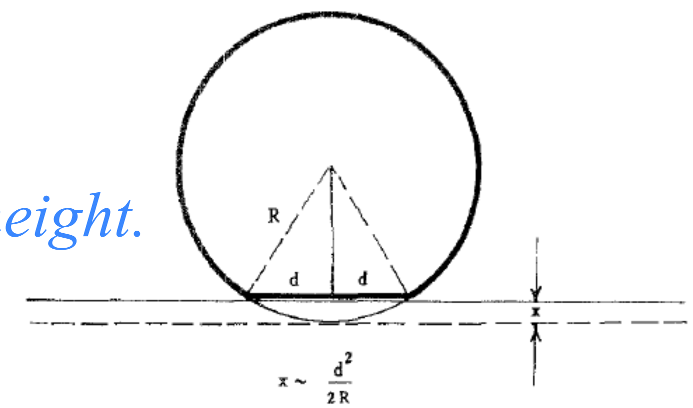

FIG. 10. Sagittal formula.

If $F(x)$ and $G(x)$ were linear for all x, then the

Collisions Involving Superballs

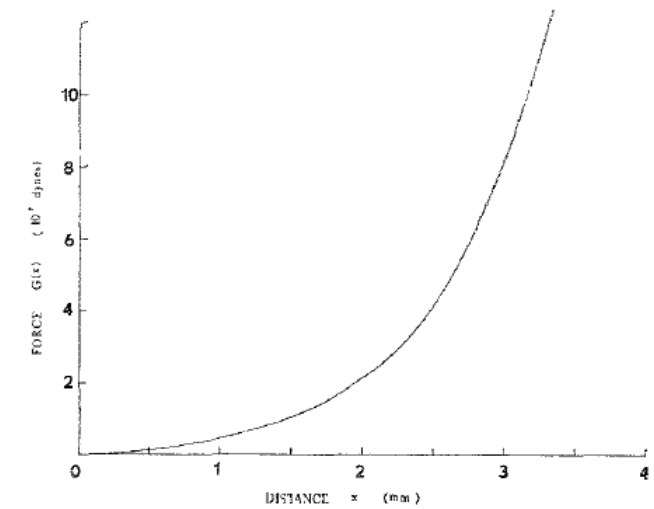

FIG. 12. Adiabatic force function $G(x)$.

Then fancy-pants computer theory can predict N-ball tower bounce

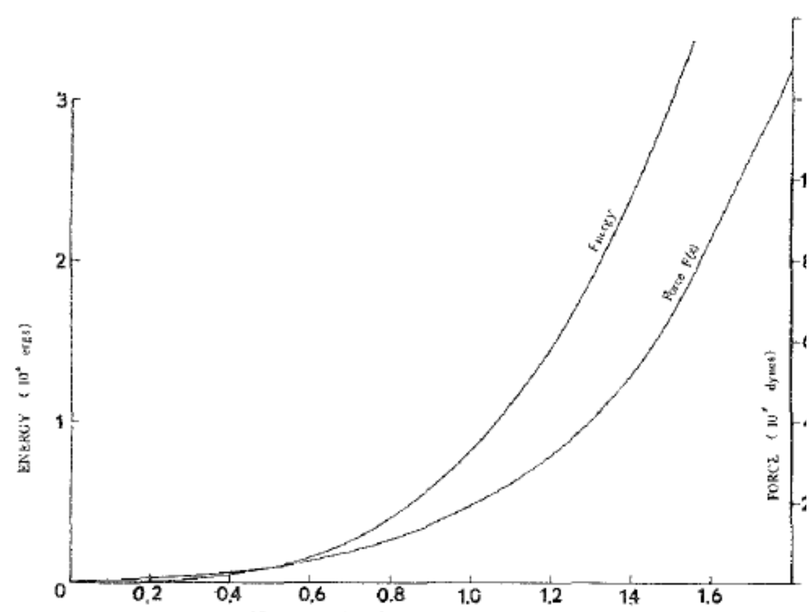

FIG. 11. Adiabatic force $F(x)$ and energy curves f[...]
Superball.

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

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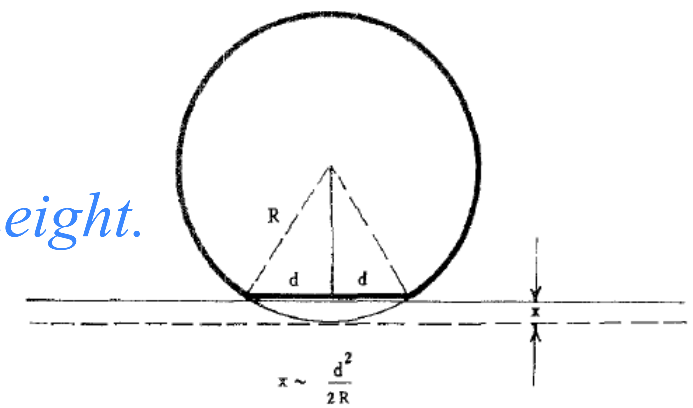

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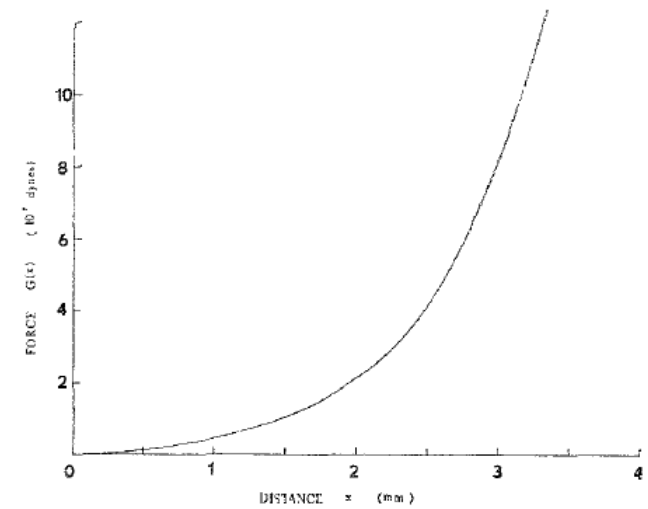


Fig. 12. Adiabatic force function $G(x)$.

If $F(x)$ and $G(x)$ were linear for all x, then the

Functions $F(x)$ and $G(x)$ were then placed on the function generators of the analog computer.

Then fancy-pants computer theory can predict N-ball tower bounce

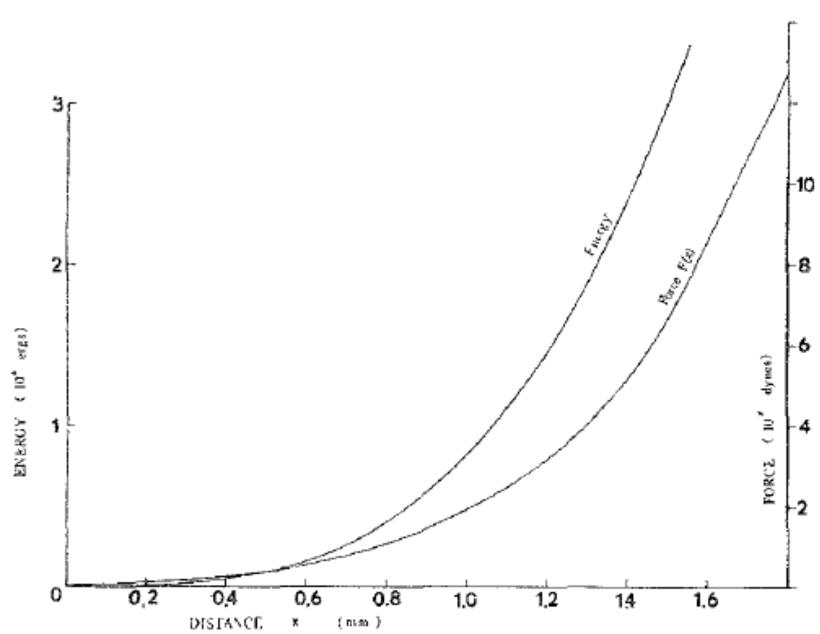
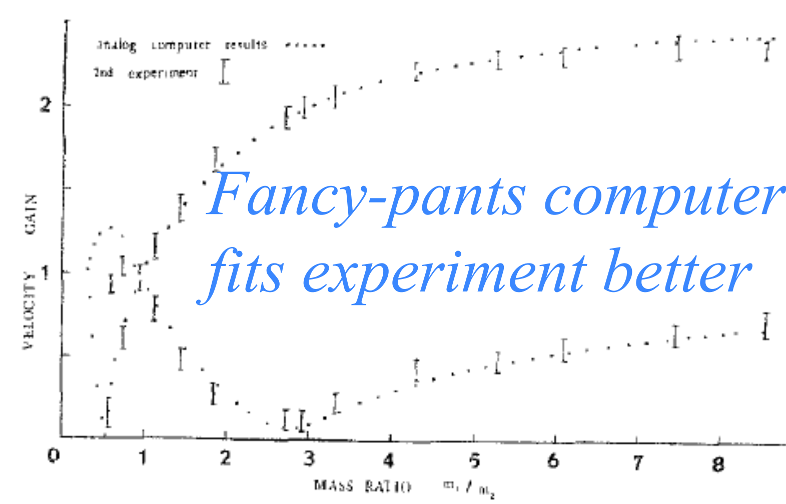


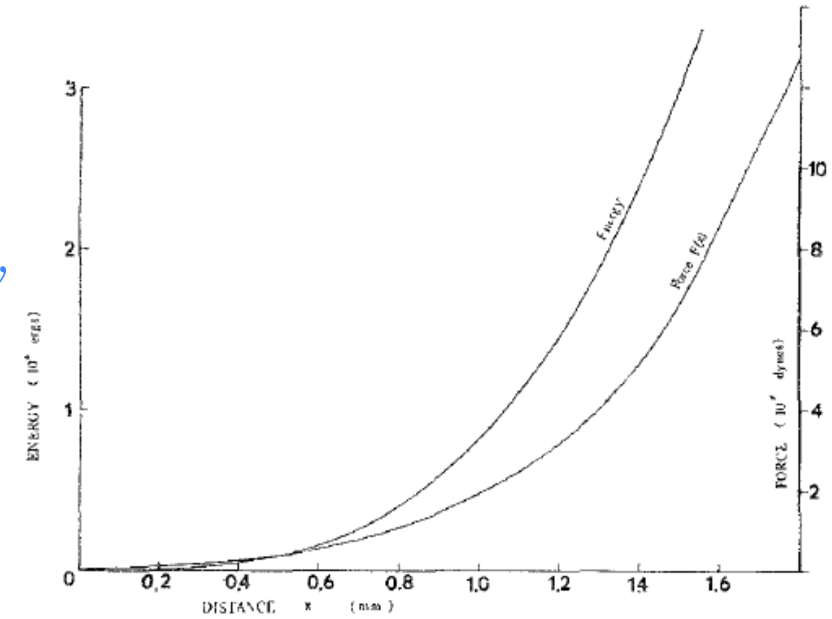
Fig. 11. Adiabatic force $F(x)$ and energy curves for Superball.



Fancy-pants computer theory fits experiment better

Fig. 13. Comparison between analog computer gain curves and second experiment.

Then fancy-pants computer theory can predict N-ball tower bounces



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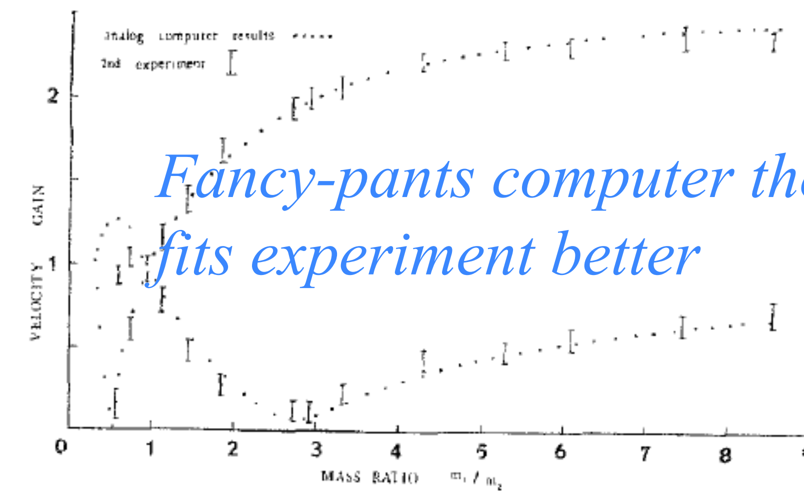

FIG. 13. Comparison between analog computer gain curves and second experiment.

Here are some 3-ball tower bounce predictions

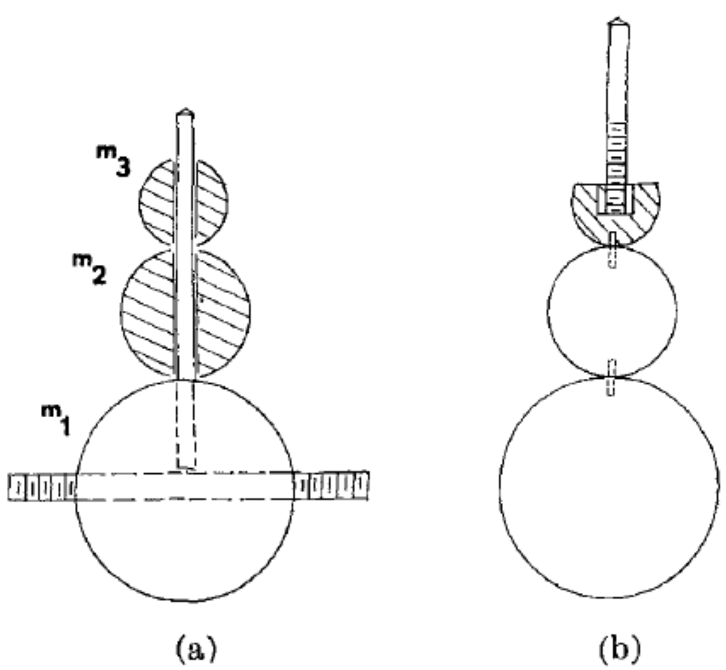

FIG. 14. Two designs for a multiple stage tower of balls. (a) Large number of balls can slide on a shaft. (b) Balls connected by small pins stand to lose appreciable amounts of binding energy.

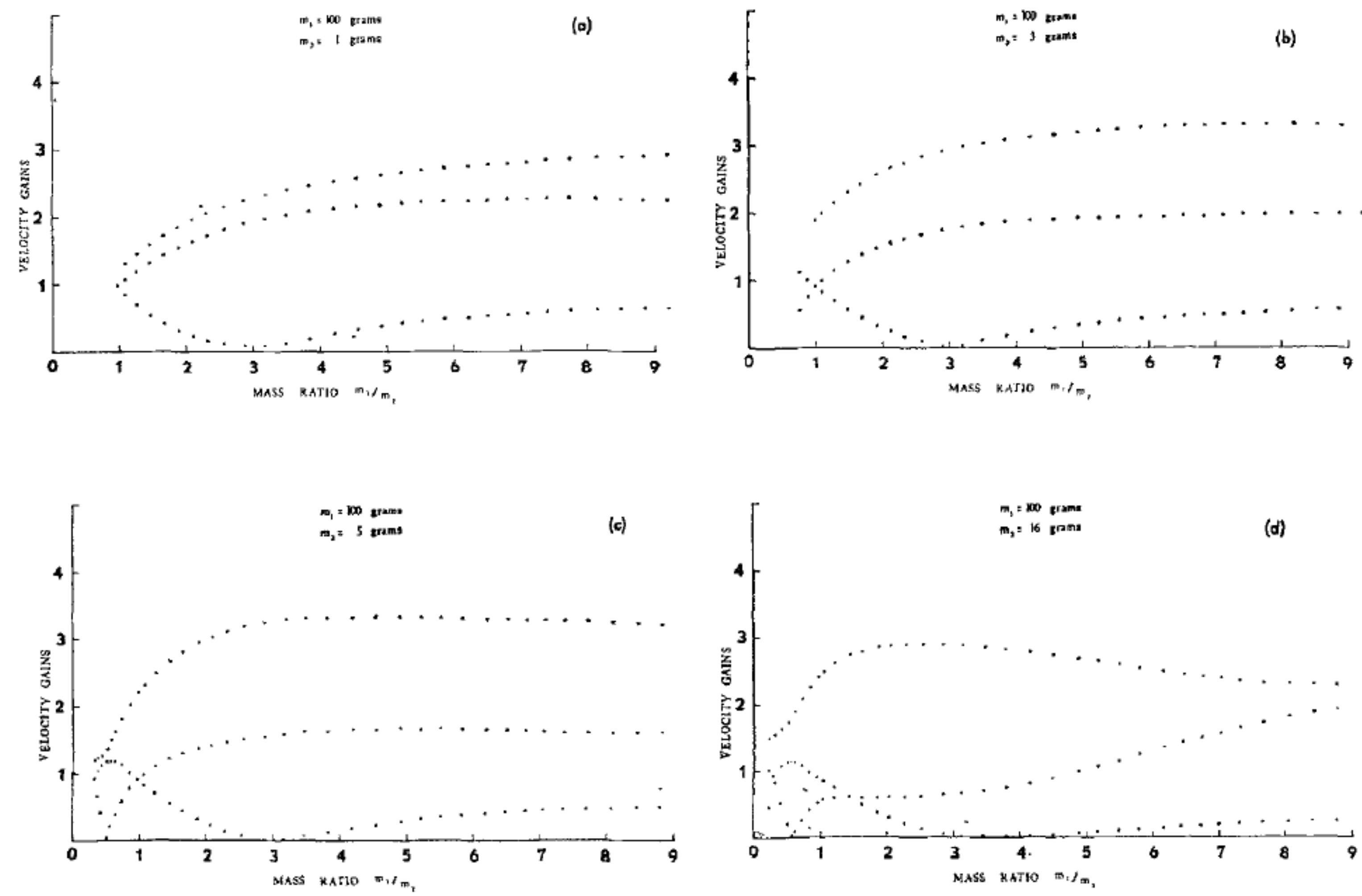

FIG. 15. (a)–(d) Analog computer output for velocity gains of three-ball system.

Potential energy dynamics of Superballs and related things

Thales geometry and "Sagittal approximation" to force law

Geometry and dynamics of single ball bounce

(a) Constant force F=-k (linear potential V=kx)

Some physics of dare-devil-diving 80 ft. into kidee pool *(Simulations)*

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Geometry and potential dynamics of 2-ball bounce

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→ *Geometry and dynamics of n-ball bounces*

(Leads to Sagittal potential analysis of 2, 3, and 4 body towers)

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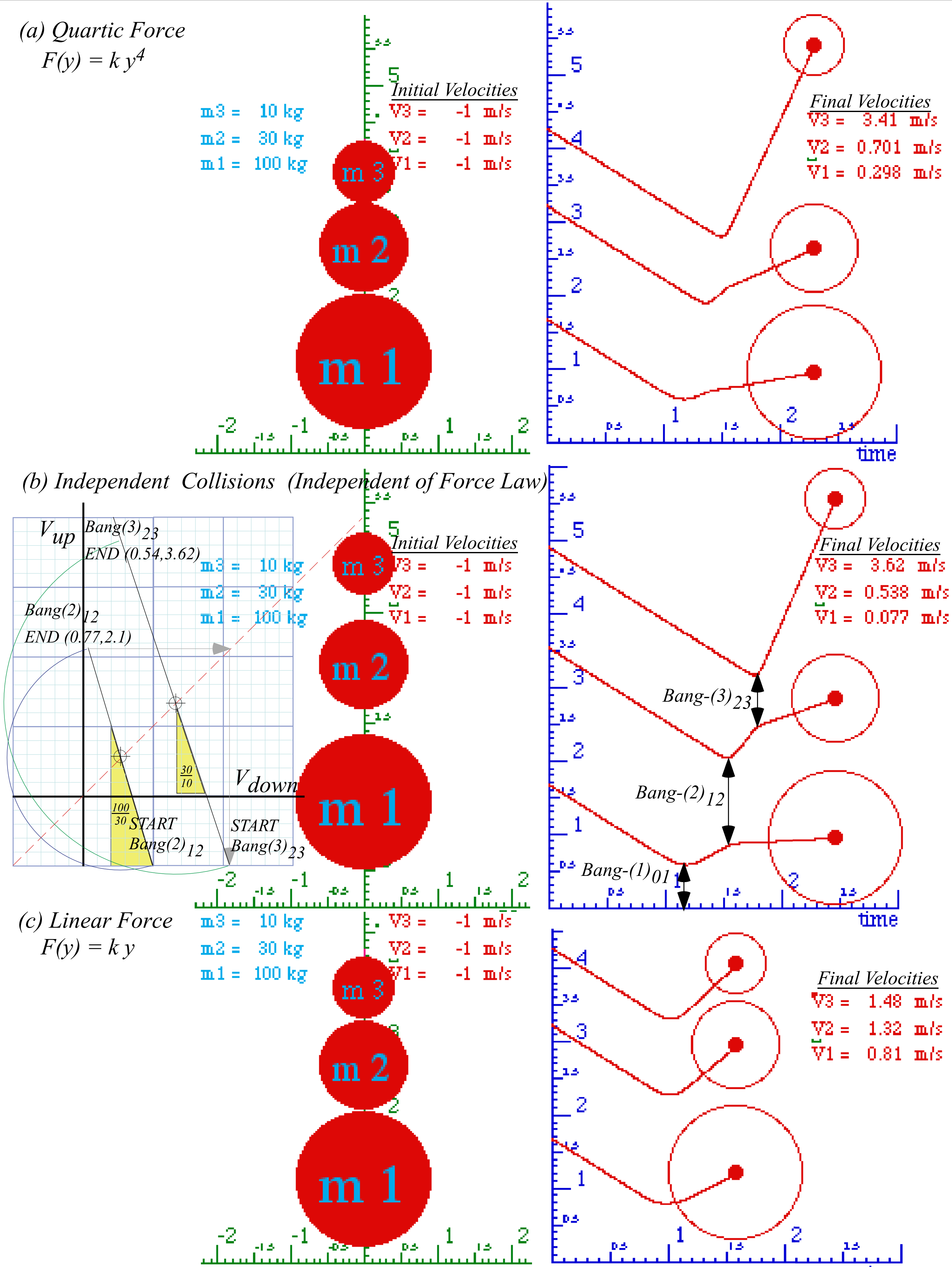
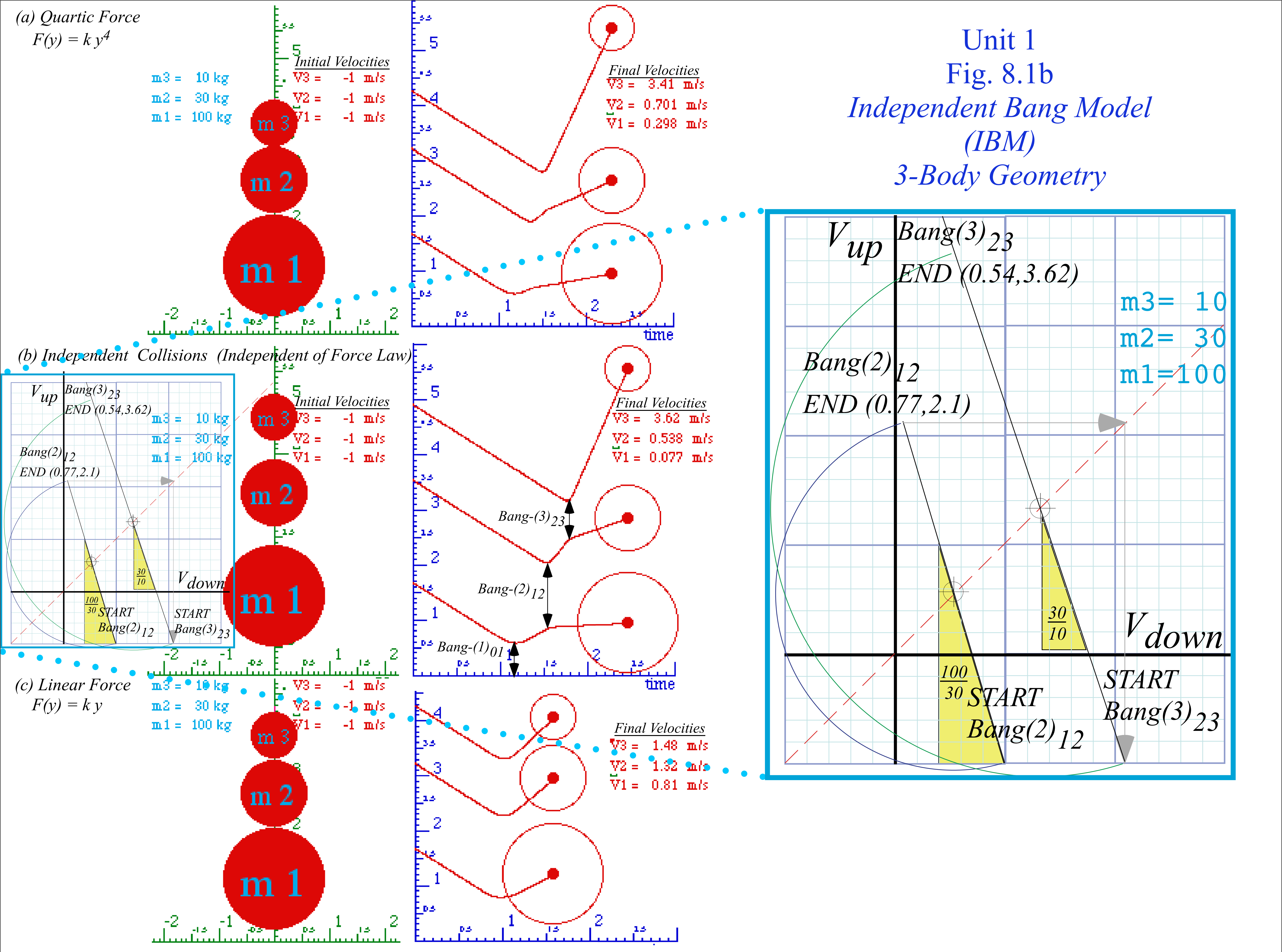


Unit 1
Fig. 8.1a-c
Independent Bang Model (IBM)
3-Body Geometry

[BounceIt Simulation: 3-Ball Tower w/ Quartic Force]

[BounceIt Simulation: 3-Ball Tower w/ Linear Force]

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



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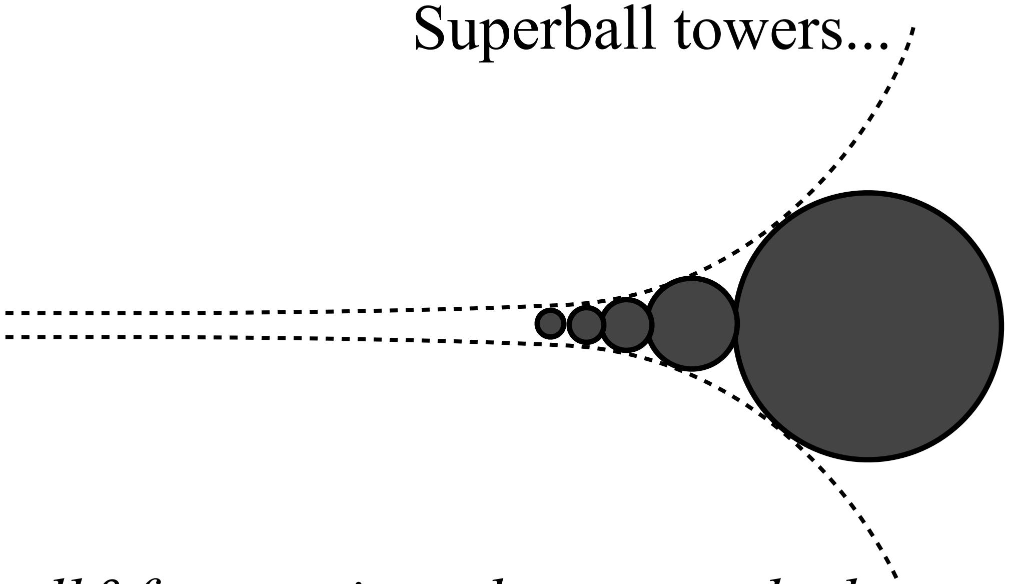
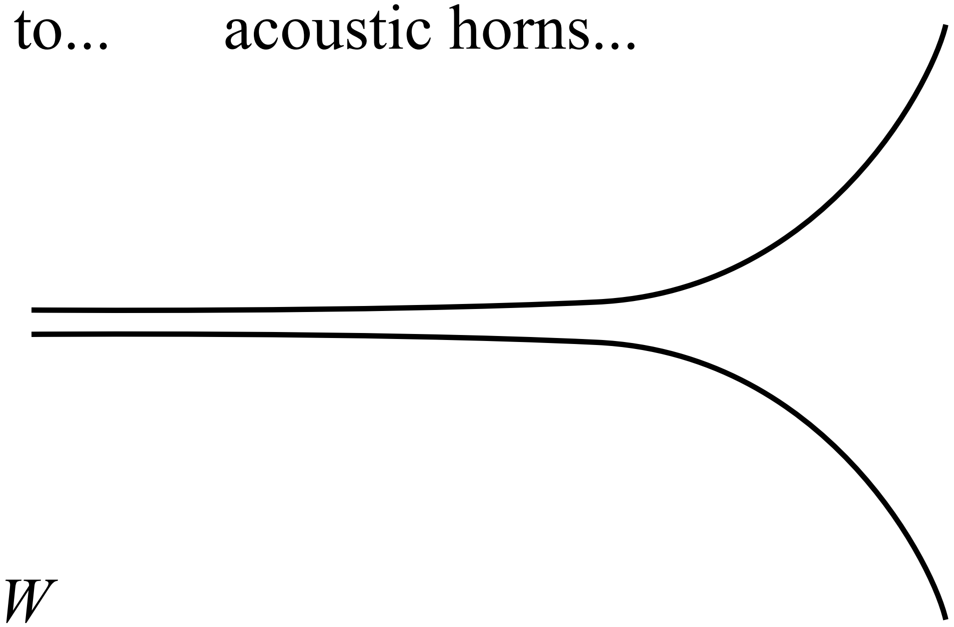
Bouncing columns and Newton's cradle

Inelastic examples: "Zig-zag geometry" of freeway crashes

*Super-elastic examples: This really **is** "Rocket-Science"*

Superball towers... analogous to... acoustic horns...





small&fast… impedance matched to… BIG&SLOW

[6] J. B. Hart and R. B. Herrmann, Amer. J. Phys. **36**, 46 (1968).

1.8.3 *The optimal idler (An algebra/calculus problem)*
To get highest final v_3 of mass m_3 find optimum mass m_2 in terms of masses m_1 and m_3 that does that.

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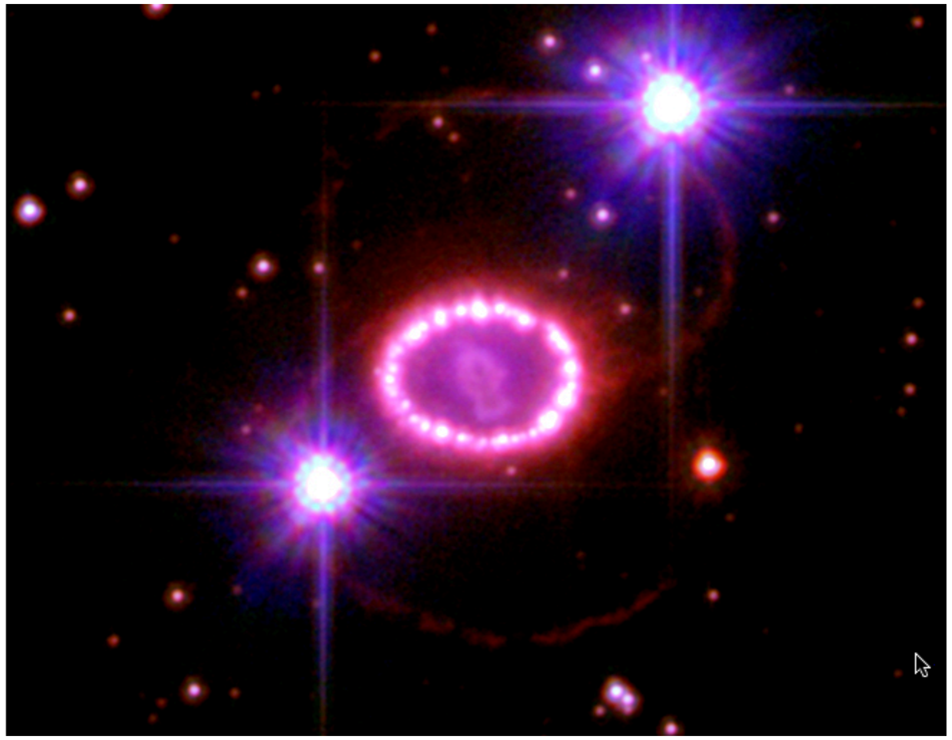
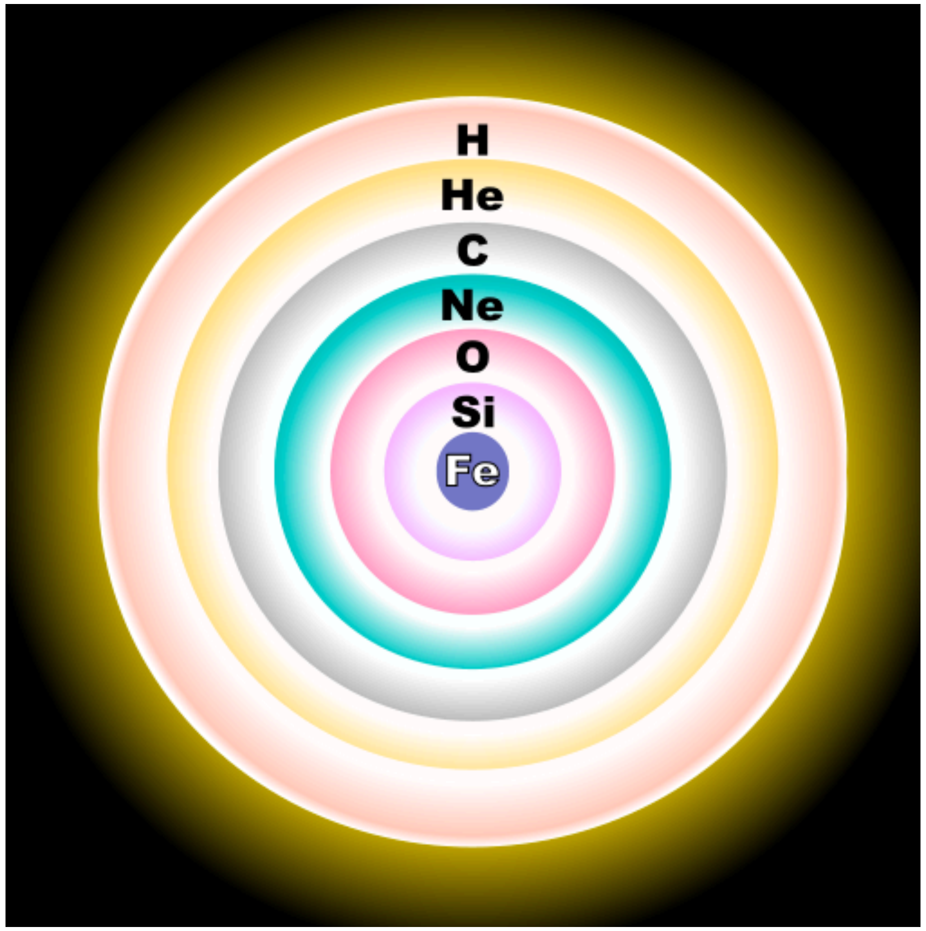


Source

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

Author

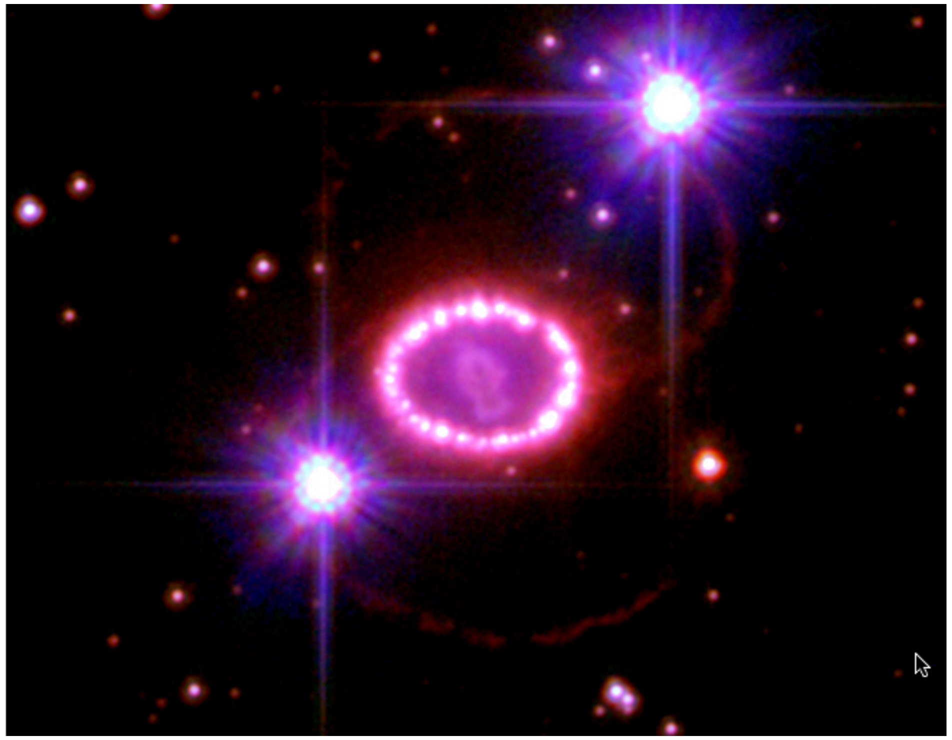
NASA, ESA, P. Challis, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)



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

Process	Main fuel	Main products	25 M☉ star[6]		
			Temperature (Kelvin)	Density (g/cm^3)	Duration
hydrogen burning	hydrogen	helium	7×10^7	10	10^7 years
triple-alpha process	helium	carbon, oxygen	2×10^8	2000	10^6 years
carbon burning process	carbon	Ne, Na, Mg, Al	8×10^8	10^6	10^3 years
neon burning process	neon	O, Mg	1.6×10^9	10^7	3 years
oxygen burning process	oxygen	Si, S, Ar, Ca	1.8×10^9	10^7	0.3 years
silicon burning process	silicon	nickel (decays into iron)	2.5×10^9	10^8	5 days

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



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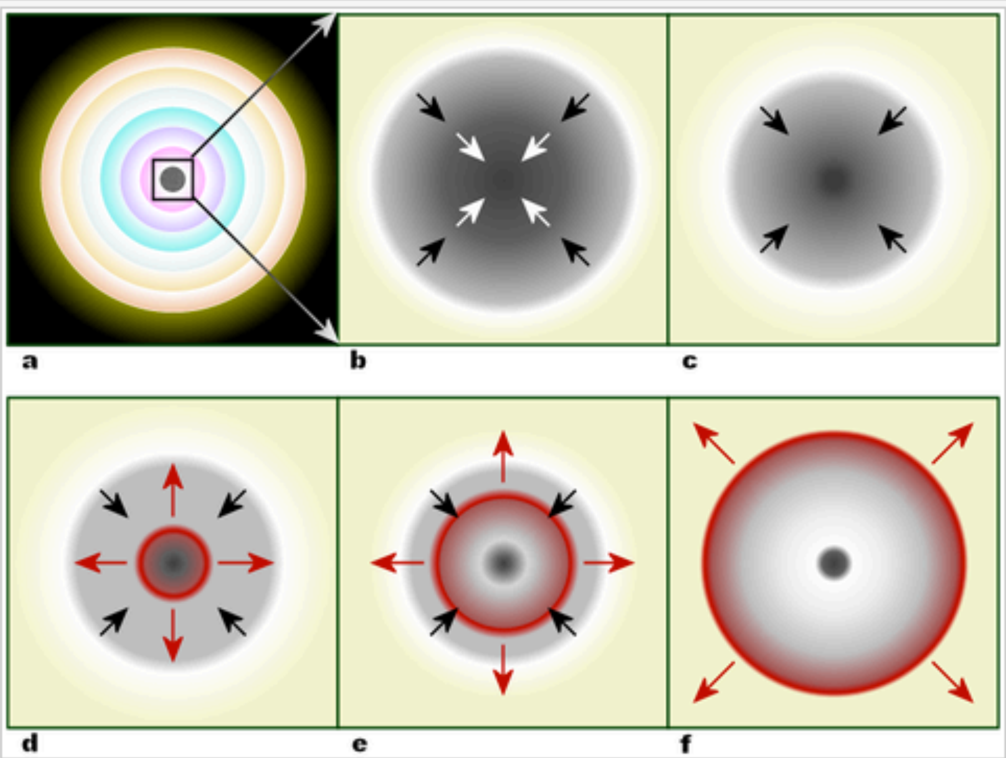
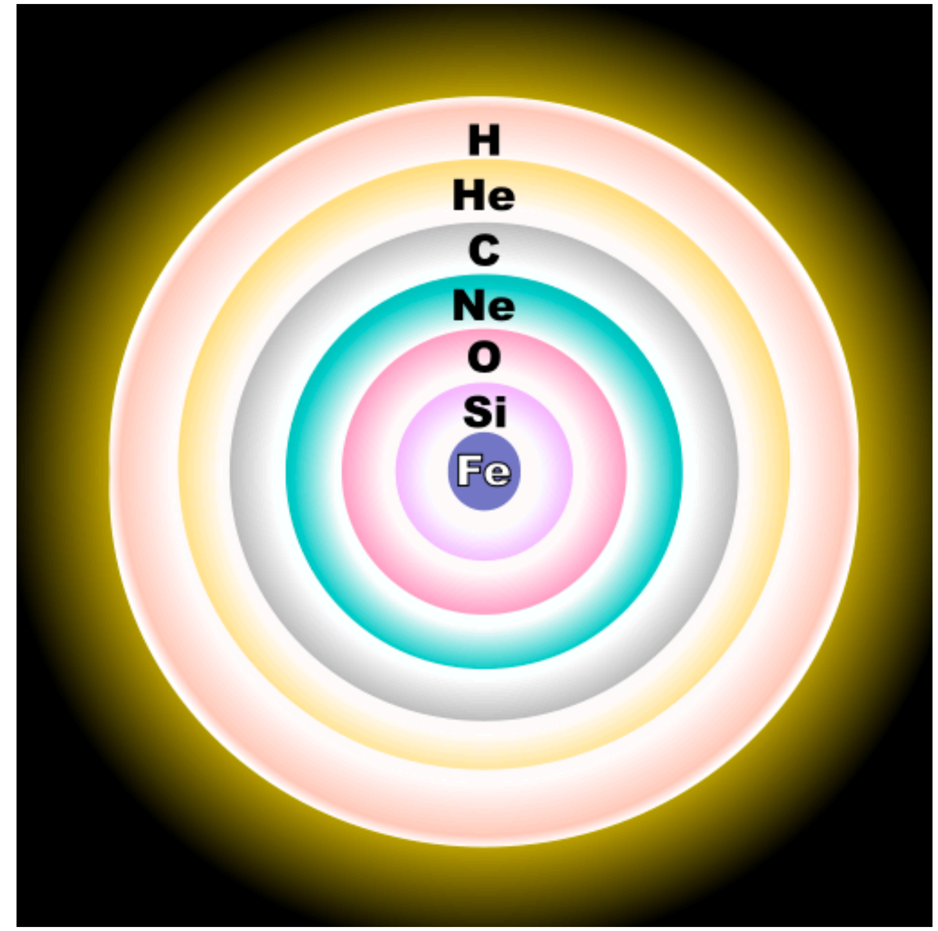


Within a massive, evolved star (a) the onion-layered shells of elements undergo fusion, forming a nickel-iron core (b) that reaches Chandrasekhar-mass and starts to collapse. The inner part of the core is compressed into neutrons (c), causing infalling material to bounce (d) and form an outward-propagating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



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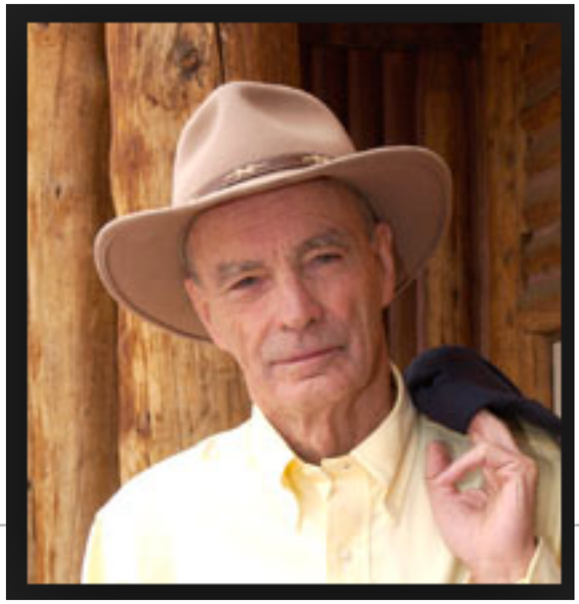
Stirling Colgate



From Wikipedia, the free encyclopedia

Stirling Auchincloss Colgate (November 14, 1925 – December 1, 2013) was an American physicist at Los Alamos National Laboratory and a professor emeritus of physics, past president at the New Mexico Institute of Mining and Technology (New Mexico Tech),[1] and an heir to the Colgate toothpaste family fortune.[2] He was America's premier[citation needed] diagnostician of thermonuclear weapons during the early years at the Lawrence Livermore National Laboratory in California. While much of his involvement with physics is still highly classified, he made many contributions in the open literature including physics education and astrophysics.[3] He was born in New York City in 1925, to Henry Auchincloss and Jeanette Thurber (née Pruyn) Colgate.[4]

..an amusing off-color aside
story of Stirling Colgate's NMIMT resignation...

(Not told in Wikipedia!)

Quote

- "*I was always enamored with explosives, and eventually I graduated to dynamite and then nuclear bombs*."

Patents

Multiple-collision accelerator assembly

US 5256071 A

ABSTRACT

A device comprising several highly elastic objects is presented whose purpose is to demonstrate an unobvious consequence of fundamental laws of physics--the acceleration of an object to high speed by multiple collisions among a series of heavier objects moving at slower speed. The objects, each of different mass, are arrayed in close proximity in order of decreasing mass with their centers lying along a straight line. This arrangement of the assembly of objects is maintained by a constraining element which permits the assembly axis to be oriented in any desired direction and permits the assembly to be moved or manipulated as a unit in any desired way without destroying the arrangement of objects. In the preferred embodiment the elastic objects are polybutadiene balls (12), the constraining element is an interior guide-pin (10) fastened in the largest ball and extending radially therefrom, on which the remaining balls can slide freely because of diametrical holes formed in them. In use this multiple-collision accelerator assembly is suspended in vertical orientation, with the largest ball downward, by holding the tip-end of the guide-pin which extends beyond the littlest ball. The assembly is then dropped onto a solid surface (14), the striking of which produces a sharp impulse that is transmitted from the largest ball, through the assembly, causing the littlest ball to be projected to a height many times that from which the assembly was dropped.

(Point allowing patent over previous 1973 proposal (4))

Publication number	US5256071 A
Publication type	Grant
Application number	US 07/748,804
Publication date	Oct 26, 1993
Filing date	Aug 22, 1991
Priority date ?	Aug 22, 1991
Fee status ?	Paid
Inventors	Edward W. Hones, William G. Hones, Stirling A. Colgate
Original Assignee	Hones Edward W, Hones William G, Colgate Stirling A
Export Citation	BiBTeX, EndNote, RefMan

Patent Citations (3), Referenced by (4), Classifications (7), Legal Events (7)

External Links: USPTO, USPTO Assignment, Espacenet

AstroBlaster
Product Code: AstroBlaster
Our Price: $9.95

1st publication describing theory and experiment of this device 20 years before.

Velocity Amplification in Collision Experiments Involving Superballs

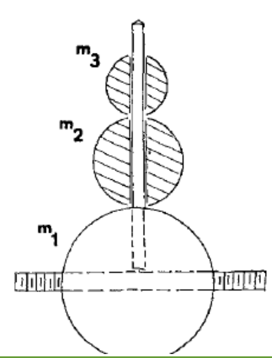
William G. Harter[1] (class of WGH)

— HIDE AFFILIATIONS

[1] University of Southern California, Los Angeles, California 90007

View the Scitation page for University of Southern California (USC).

Am. J. Phys. **39**, 656 (1971); http://dx.doi.org/10.1119/1.1986253



BUY: $30.00

(Now I have to pay APS for my own paper.)

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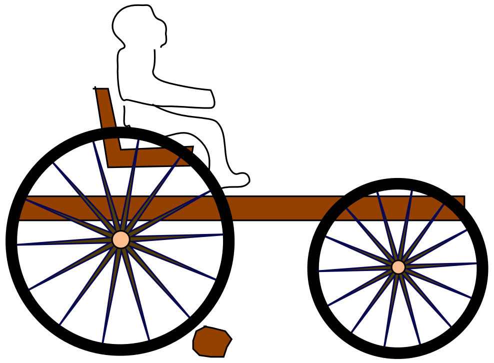
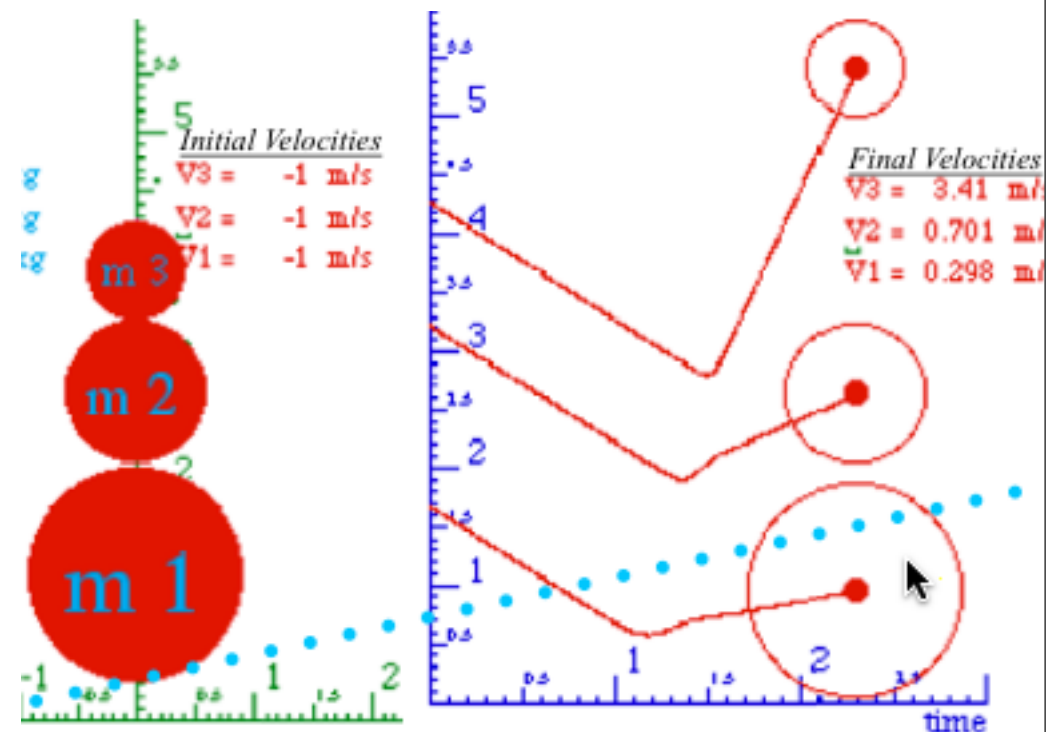
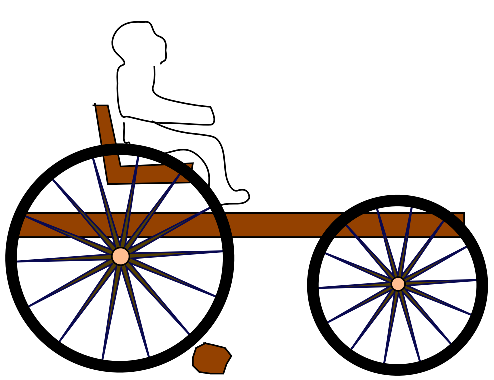
Western buckboard = ?????

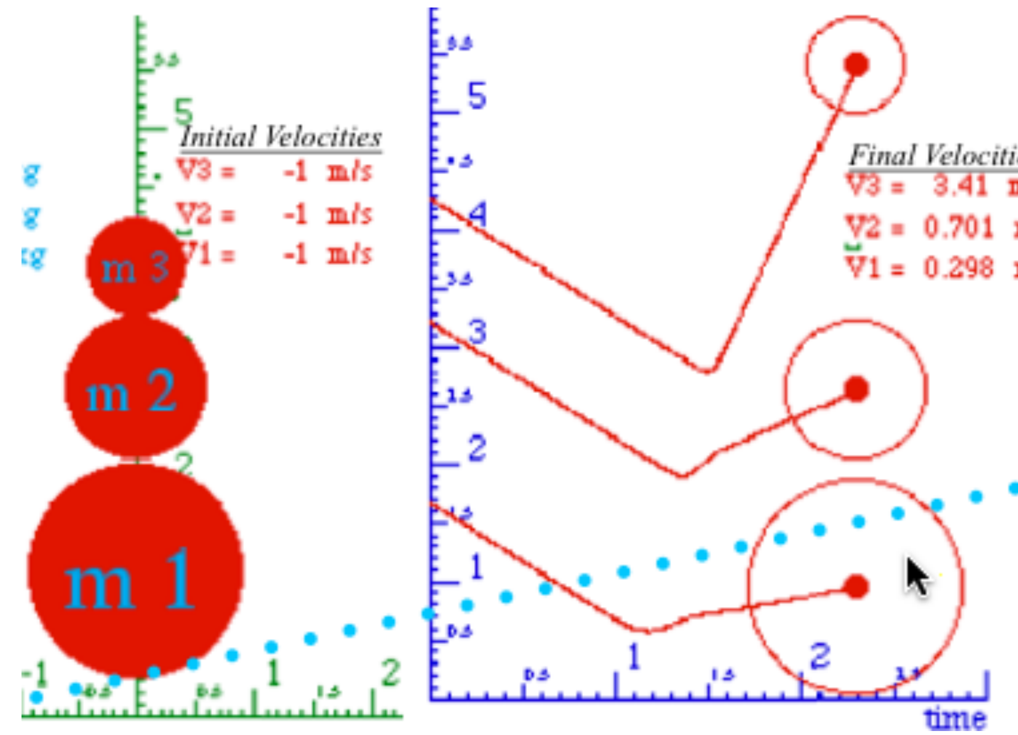
Western buckboard = *?????*



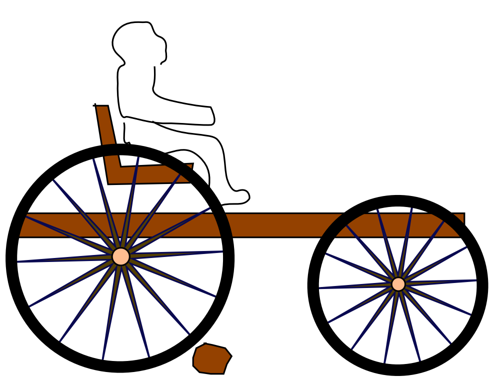


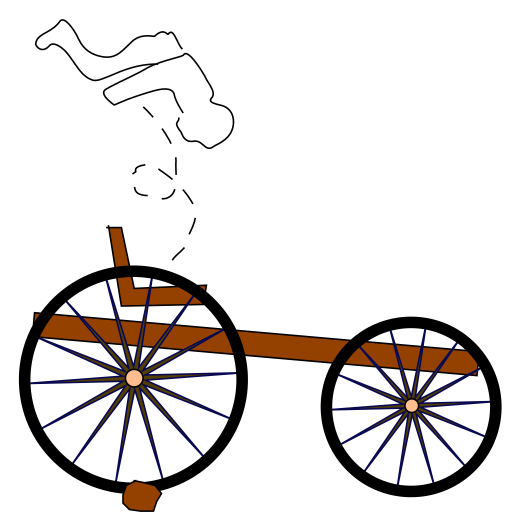
Western buckboard = *3-ball analogy*





Western buckboard = *3-ball analogy* *Disaster!*





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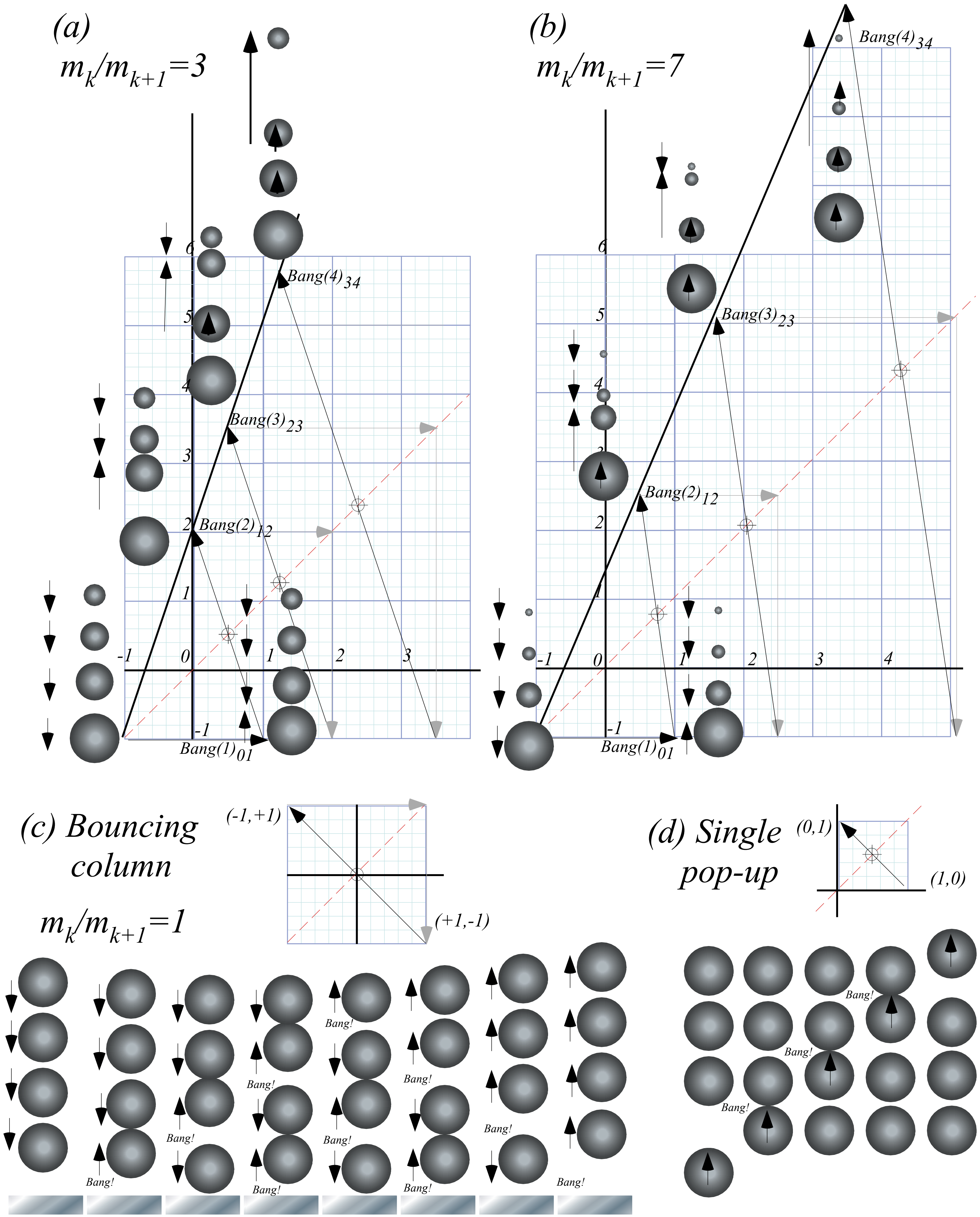
Super-elastic examples: This really ***is*** *"Rocket-Science"*

Unit 1
Fig. 8.2a-b
4-Body IBM Geometry
Fig. 8.2c-d
4-Equal-Body Geometry



[BounceIt Simulation: 4-Ball Tower w/ m_k/m_{k+1} = 3]

4-Equal-Body
"Shockwave" or pulse wave
Dynamics

Opposite of continuous wave dynamics introduced in Unit 2

[BounceIt Simulation: 4-Ball Tower w/ m_k/m_{k+1} = 1]

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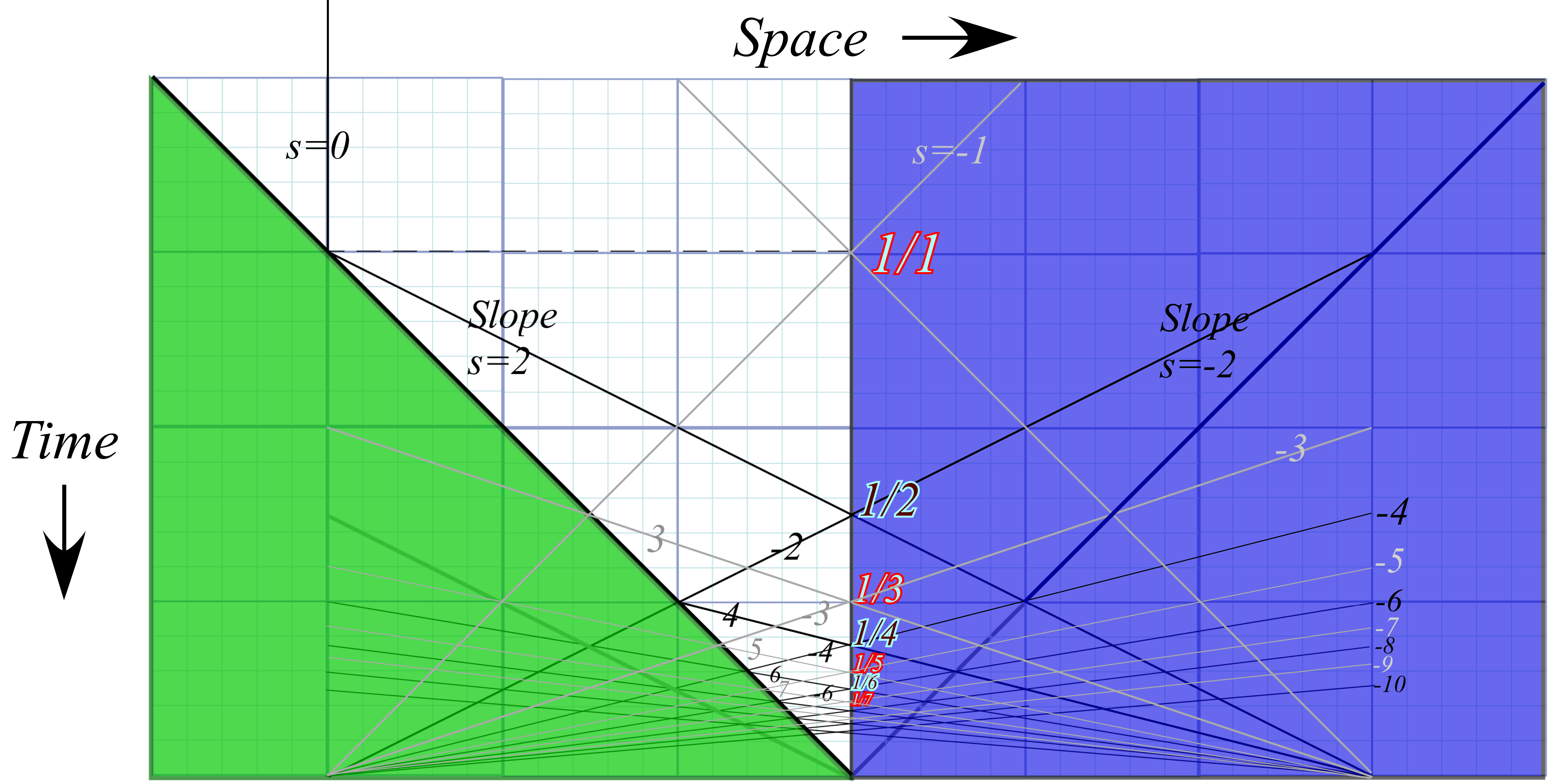
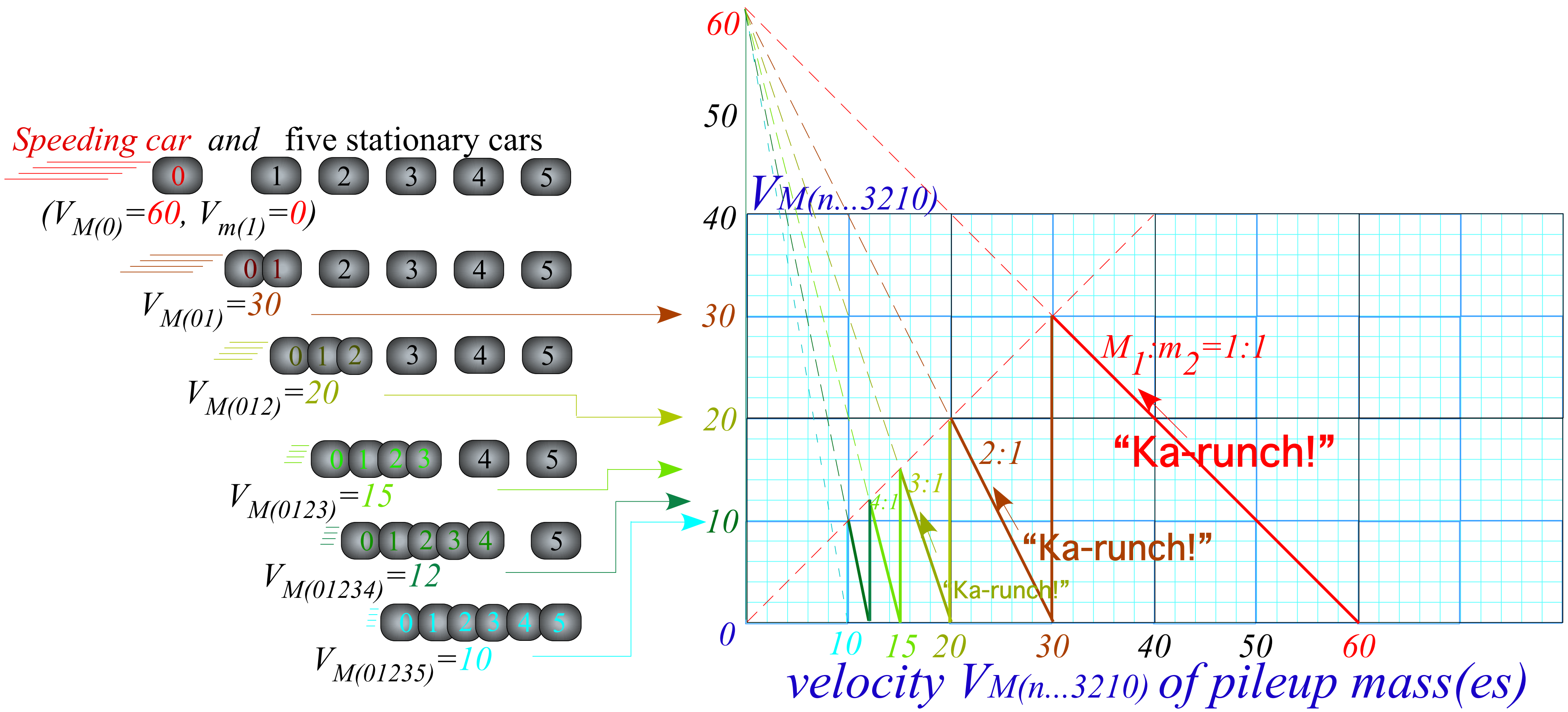
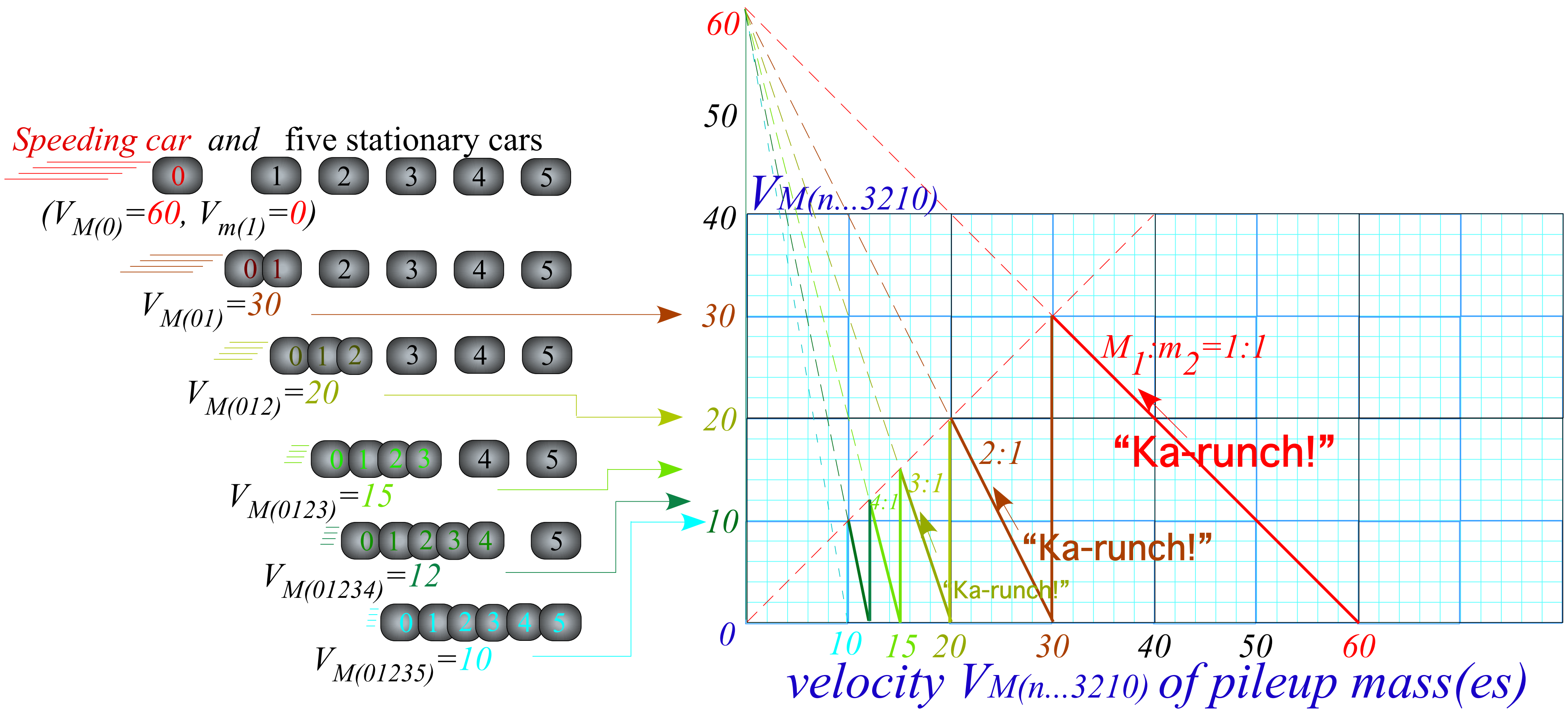
First recall "zig-zag" fractions of "Monster Mash" in Lect. 4

Trajectory geometry exposed (Harmonic series 1/1,1/2,1/3,1/4,...)





Unit 1
Fig. 8.5
Pile-up:
One *60mph* car
hits
five standing cars



Unit 1

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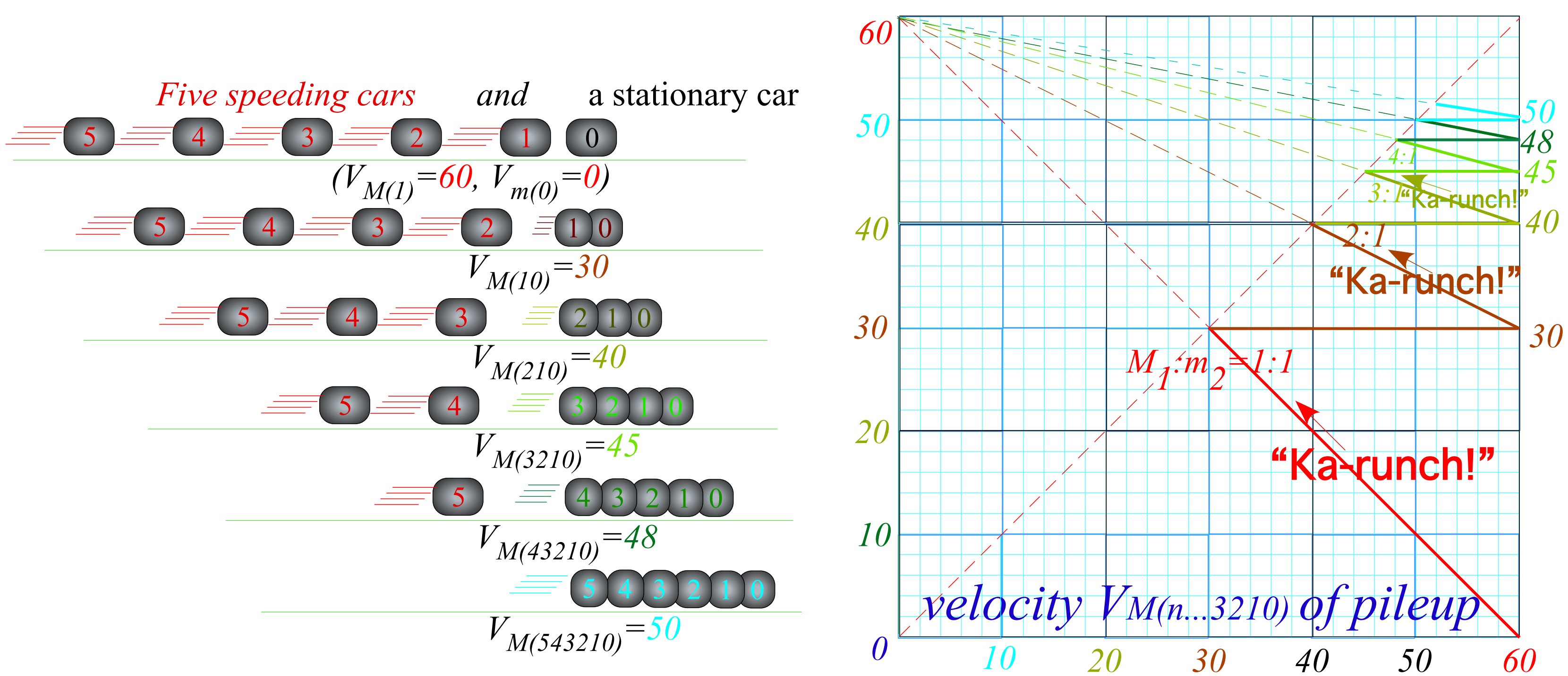
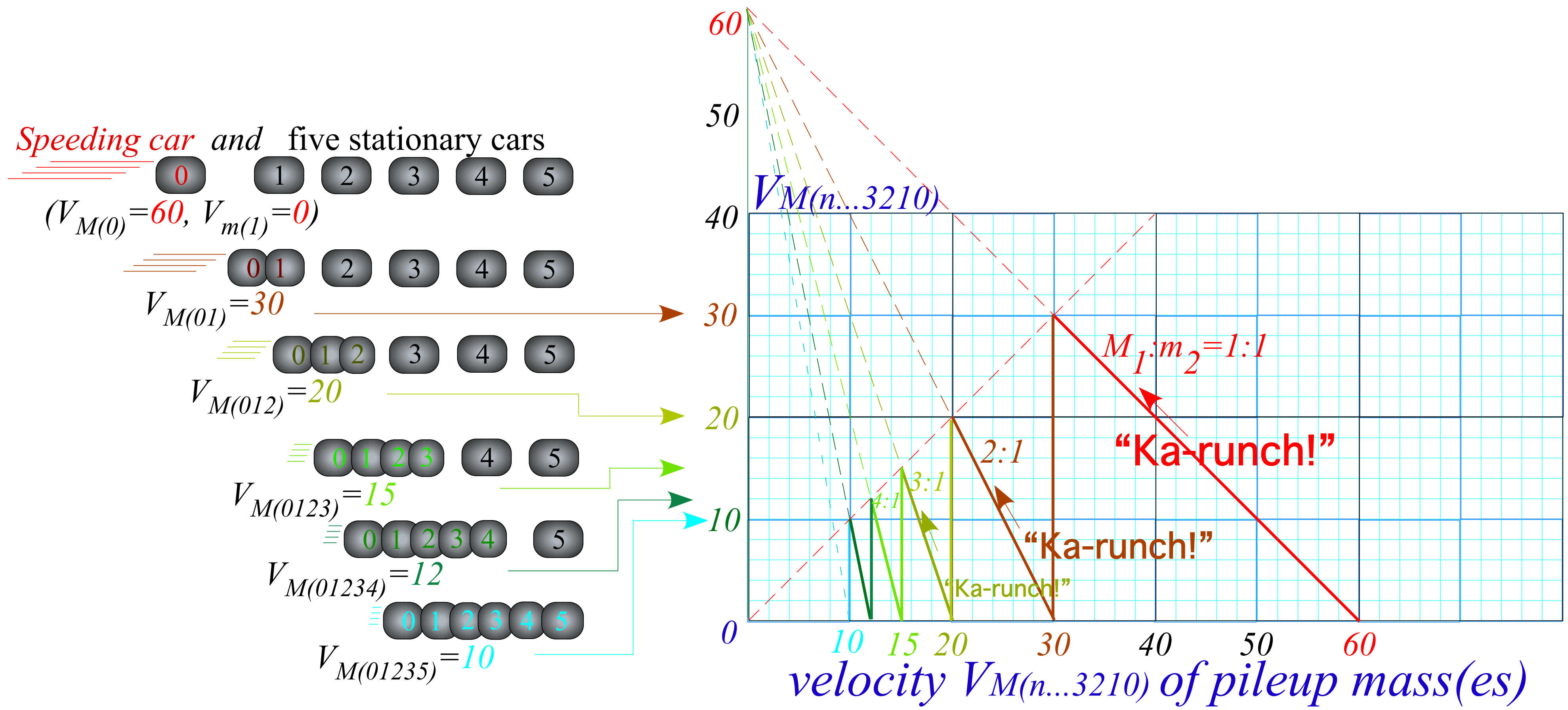


Fig. 8.6
Pile-up:
Five *60mph* cars
hit
one standing cars

Unit 1



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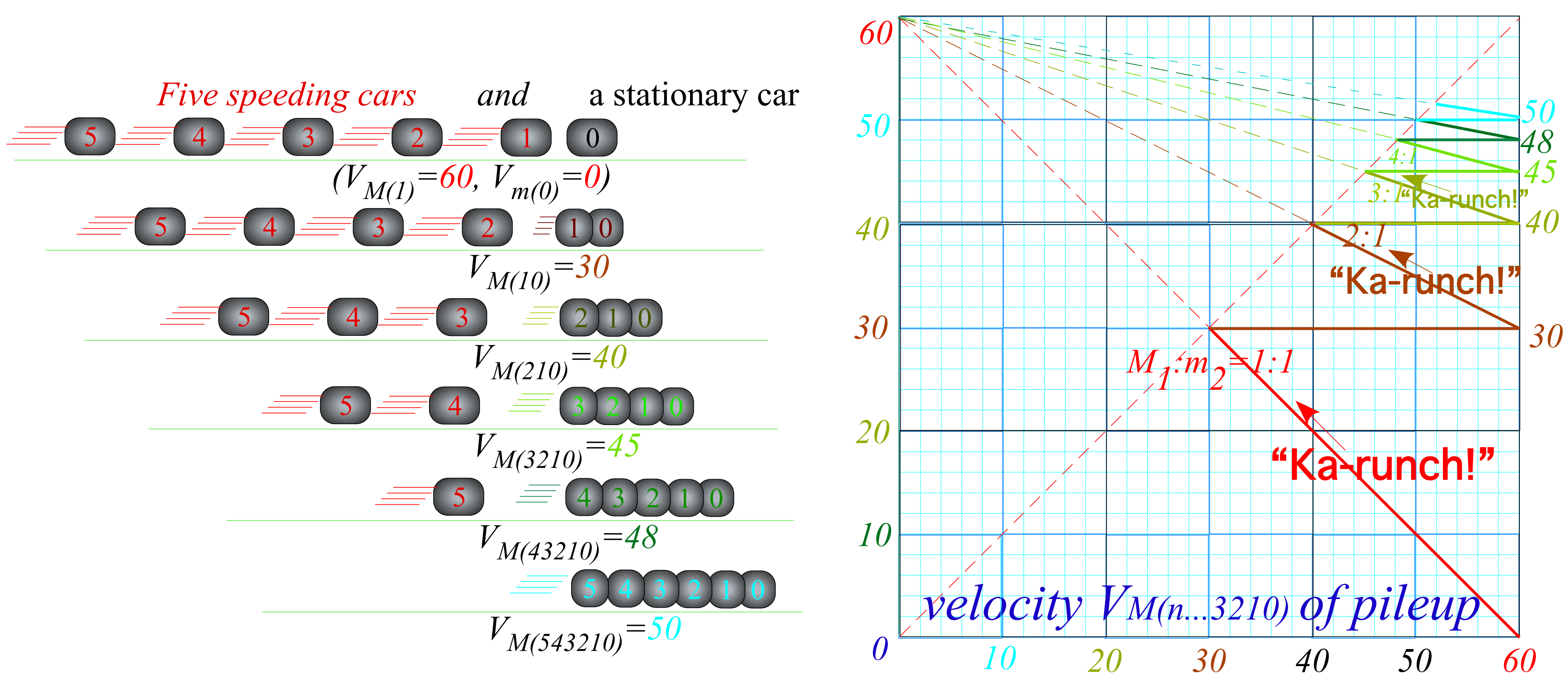

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hit
one standing cars

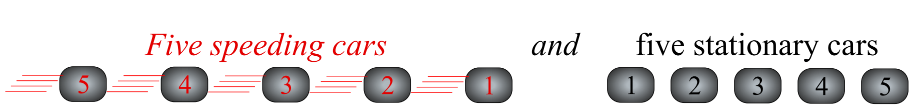

Fig. 8.7
Pile-up:
Five *60mph* cars
hit
five standing cars

(Fug-gedda-aboud-dit!!)

(Many possible scenarios depending on initial positions!)

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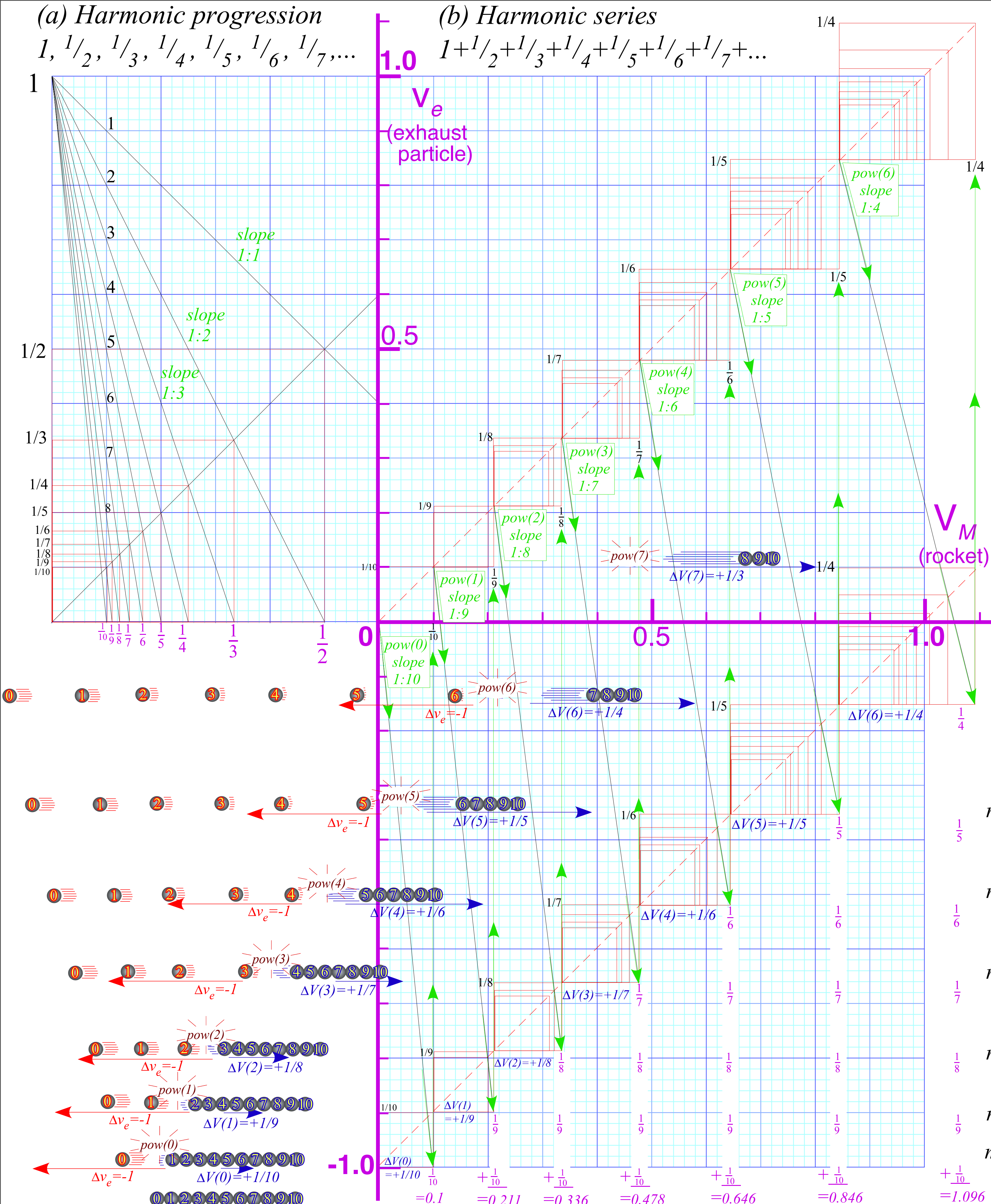
Unit 1
Fig. 8.8a-b

Rocket Science!



$$m\cdot\Delta v_7+3m\cdot\Delta V_M(7)=0$$

$$m\cdot\Delta v_6+4m\cdot\Delta V_M(6)=0$$

$$m\cdot\Delta v_5+5m\cdot\Delta V_M(5)=0$$

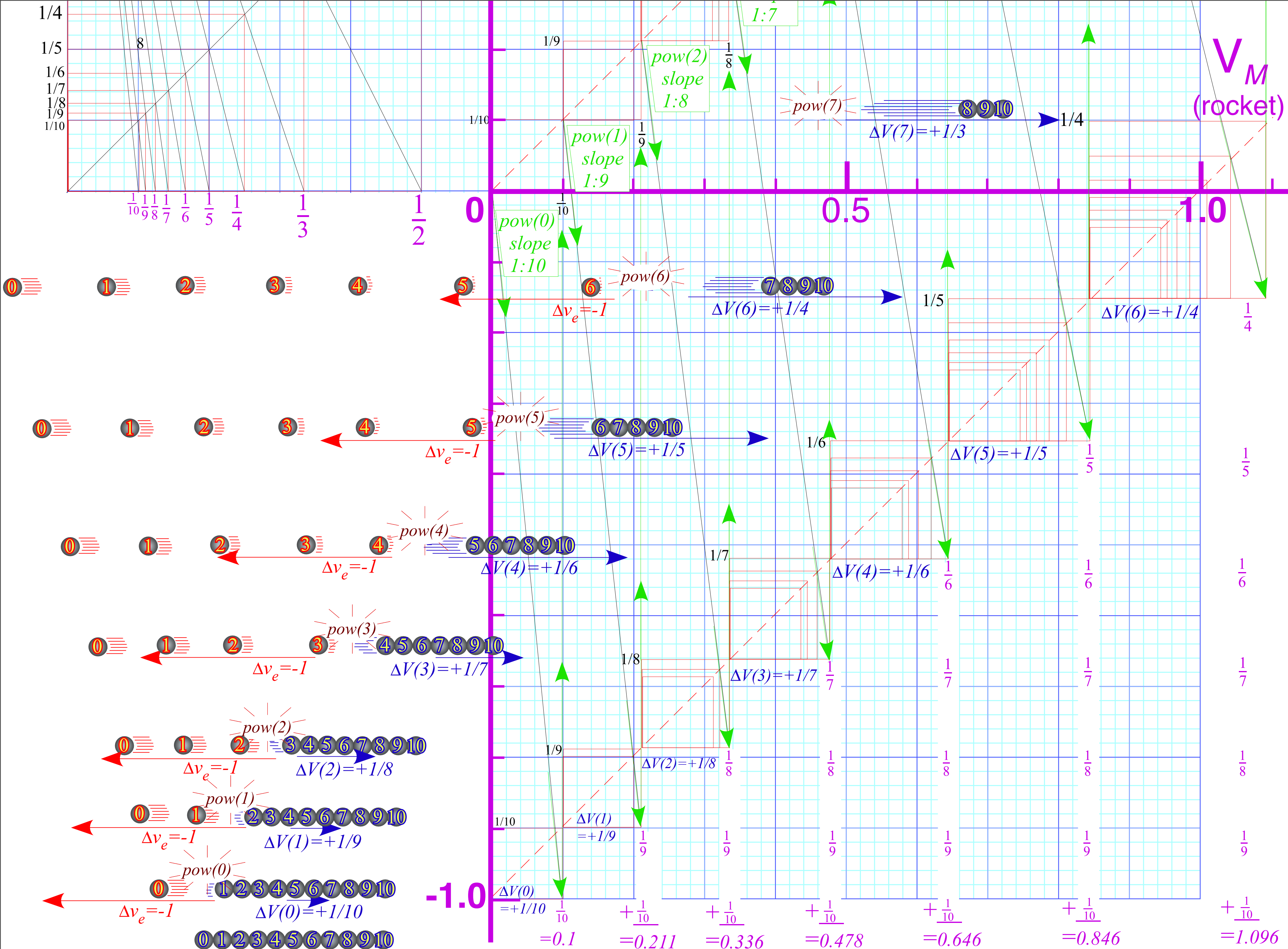
$$m\cdot\Delta v_4+6m\cdot\Delta V_M(4)=0$$

$$m\cdot\Delta v_3+7m\cdot\Delta V_M(3)=0$$

$$m\cdot\Delta v_2+8m\cdot\Delta V_M(2)=0$$

$$m\cdot\Delta v_1+9m\cdot\Delta V_M(1)=0$$

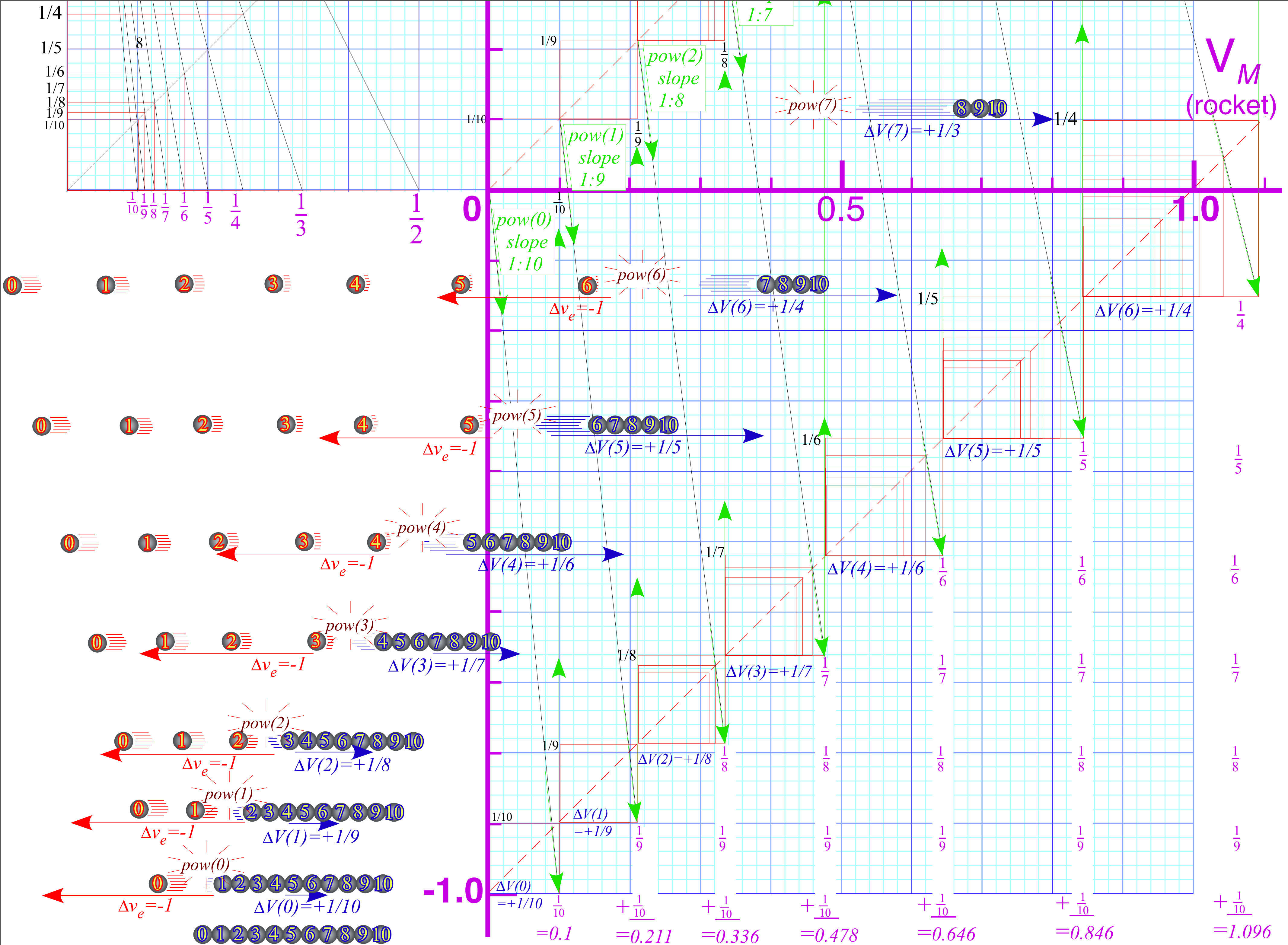
$$m\cdot\Delta v_0+10m\cdot\Delta V_M(0)=0$$



0^{th}: $V(0)=1/10=0.1$ 1^{st}: $V(1)=1/10+1/9=0.211$ 2^{nd}: $V(2)=1/10+1/9+1/8=0.336$

3^{rd}: $V(3)=V(2)+1/7=0.478$ 4^{th}: $V(4)=V(3)+1/6=0.646$ 5^{th}: $V(5)=V(4)+1/5=0.846$

6^{th}: $V(6)=V(5)+1/4=1.096$ 7^{th}: $V(7)= V(6)+1/3=1.429$ 8^{th}: $V(8)=V(7)+1/2=1.929$



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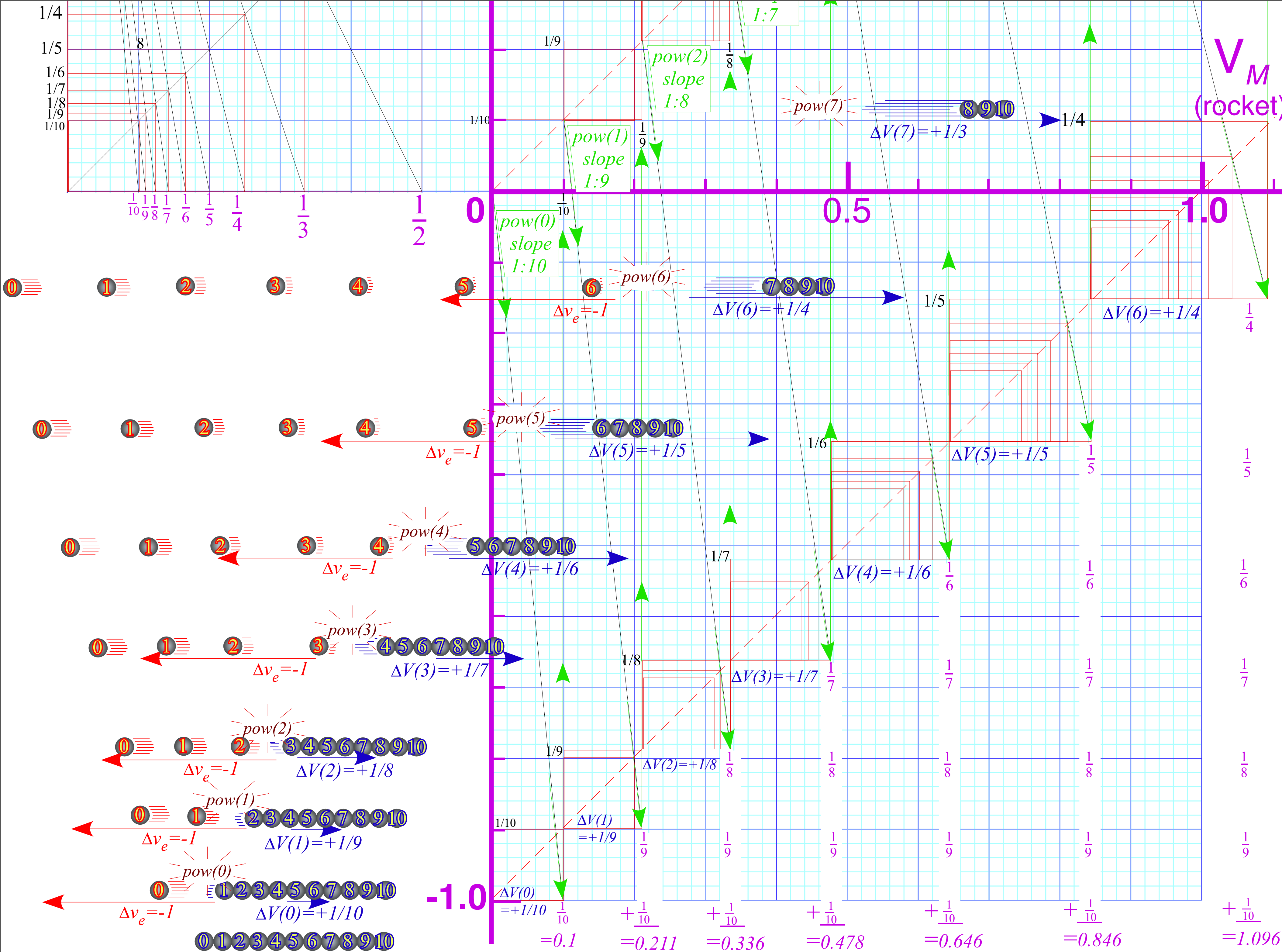
v_e *known as* **"Specific Impulse"**

By calculus: $M\cdot\Delta V=-v_e\cdot\Delta M$ or: $dV=-v_e\dfrac{dM}{M}$ Integrate: $\int_{V_{IN}}^{V_{FIN}} dV=-v_e\int_{M_{IN}}^{M_{FIN}}\dfrac{dM}{M}$



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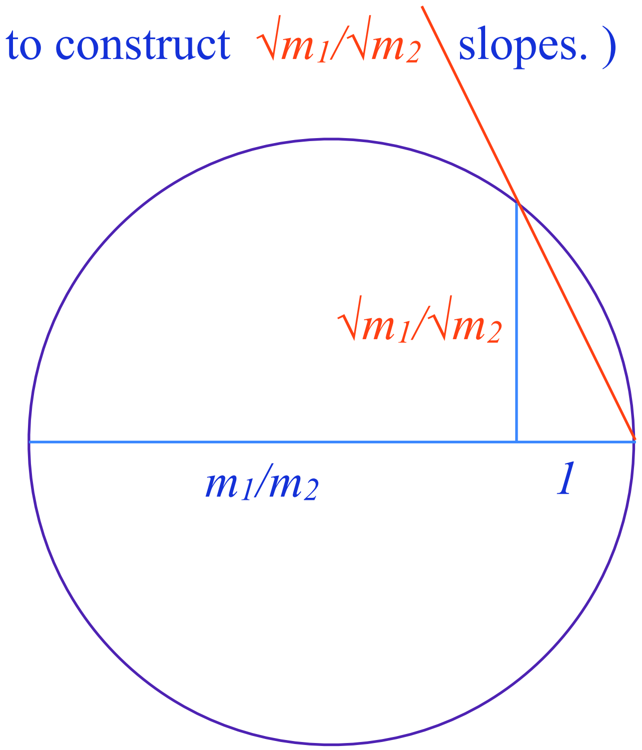
v_e *known as* **"Specific Impulse"**

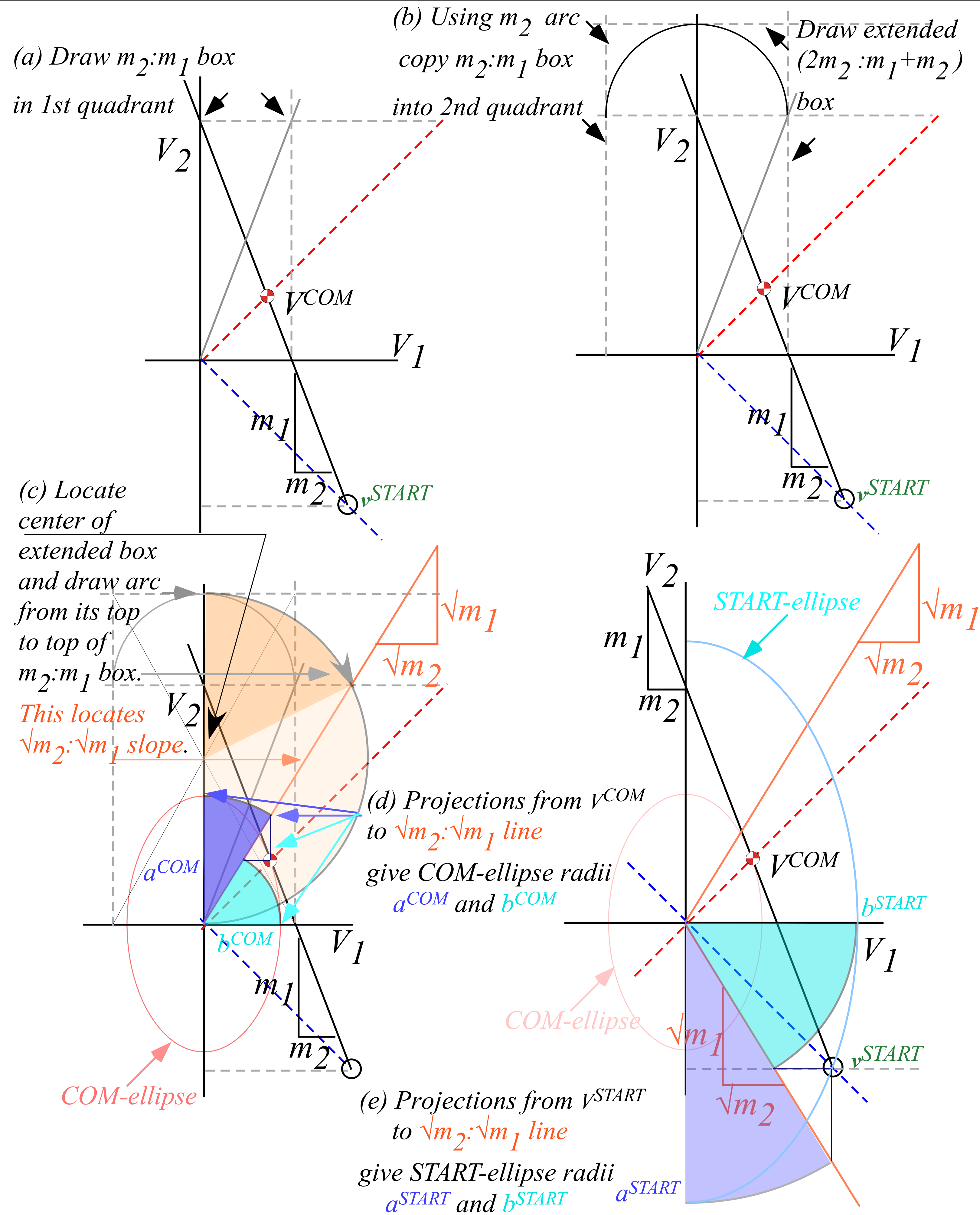
By calculus: $M\cdot\Delta V=-v_e\cdot\Delta M$ or: $dV=-v_e\dfrac{dM}{M}$ Integrate: $\int_{V_{IN}}^{V_{FIN}} dV = -v_e\int_{M_{IN}}^{M_{FIN}} \dfrac{dM}{M}$

The Rocket Equation: $V_{FIN}-V_{IN}=-v_e\left[\ln M_{FIN}-\ln M_{IN}\right]=v_e\left[\ln\dfrac{M_{IN}}{M_{FIN}}\right]$

A Thales construction for momentum-energy

(Made obsolete by Estrangian scaling to circular (V_1,V_2) plots. Still, one has to construct $\sqrt{m_1}/\sqrt{m_2}$ slopes.)





Unit 1
Fig. 8.4a-d

This is a detailed construction of the energy ellipse in a Largangian (v_1,v_2) plot given the initial (v_1,v_2).

The Estrangian (V_1,V_2) plot makes the (v_1,v_2) plot and this construction obsolete.

(Easier to just draw circle through initial (V_1,V_2).)