The Basic Bond Graph Primitives

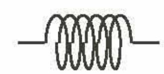
Fundamental quantities and relations

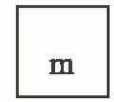
P: power e: effort f: flow $P = ef$ E: energy

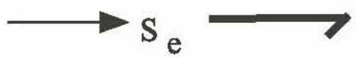
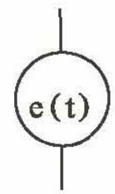
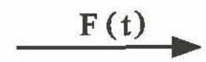
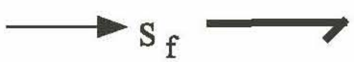
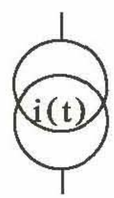
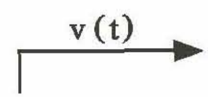
p: momentum $e = dp/dt$

q: displacement $f = dq/dt$

$E = \int e\,dq = \int f\,dp$

Bond Graph Symbol	Denotes	Electrical Network Icon	Typical Mechanical Icon
power port or bond *optional variable labels* e  f *half arrow denotes direction of positive power flow*	energetic interaction between (sub)systems	implicit	implicit
(generalized) capacitor C  effort = Φ(displacement) potential energy = E_p(displacement)	(generalized) potential energy storage	**electrical capacitor**  volts = Φ(charge) ***ideal, linear capacitor:*** $e = q/C$ $E_p = q^2/2C$	**mechanical spring**  force = Φ(displacement) ***ideal, linear spring:*** $F = k\,x$ $E_p = k\,x^2/2$

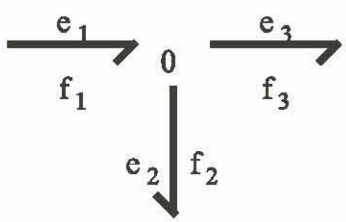
Bond Graph Symbol	Denotes	Electrical Network Icon	Typical Mechanical Icon
(generalized) inertia I  flow = Ψ(momentum) kinetic energy = E_k(momentum)	(generalized) potential energy storage	**electrical inductor**  current = Ψ(flux linkage) ***ideal, linear inductor:*** $i = \lambda / L$ $E_k = \lambda^2 / 2L$	**translational inertia**  velocity = Ψ(momentum) ***ideal, linear spring:*** $v = p/m$ $E_k = v^2/2m$
(generalized) dissipator R  effort = Γ(flow) ***inverse may also be definable***	irreversible energy removal	**electrical resistor**  volts = Γ(current) ***ideal, linear resistor:*** $e = R\ i$	**viscous damper**  force = Γ(velocity) ***ideal, linear damper:*** $F = b\ v$

Bond Graph Symbol	Denotes	Electrical Network Icon	Typical Mechanical Icon
effort source		**voltage source**	**force source**
 *optional full arrow denotes modulating signal*	boundary condition specifying effort		 (no consensus)
flow source		**current source**	**velocity source**
 *optional full arrow denotes modulating signal*	boundary condition specifying flow		 (no consensus)

Bond Graph Symbol | **Denotes** | **Electrical Network Icon** | **Typical Mechanical Icon**

zero junction

number of ports is unrestricted



net power in is zero:

$$\sum_i \sigma_i e_i f_i = 0$$

σ_i = 1 if half-arrow inwards, -1 if half-arrow outwards

Denotes: common effort connection

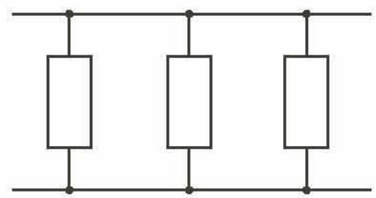
$$e_i = e_j \,,\ \forall\, i,j$$

continuity equation

$$\sum_i \sigma_i f_i = 0$$

Electrical Network Icon: **parallel connection**

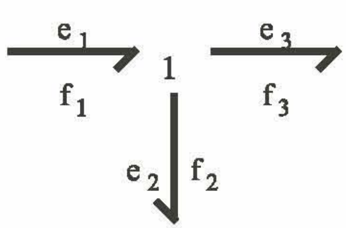
implicit in diagram



Typical Mechanical Icon: **ambiguous**

one junction

number of ports is unrestricted



net power in is zero:

$$\sum_i \sigma_i e_i f_i = 0$$

Denotes: common flow connection

$$f_i = f_j \,,\ \forall\, i,j$$

compatability equation

$$\sum_i \sigma_i e_i = 0$$

Electrical Network Icon: **series connection**

implicit in diagram

Typical Mechanical Icon: **ambiguous**

Bond Graph Symbol	Denotes	Electrical Network Icon	Typical Mechanical Icon
transformer	power-continuous energy transduction	**electrical transformer**	**mechanical lever**

transformer

$$e_1 = T\, e_2$$

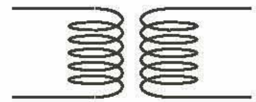
$$f_2 = T\, f_1$$

power in = power out

$$e_1 f_1 = e_2 f_2$$

power-continuous energy transduction

electrical transformer



mechanical lever

gyrator

$$e_2 = G\, f_1$$

$$e_1 = G\, f_2$$

power in = power out

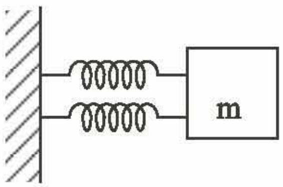
$$e_1 f_1 = e_2 f_2$$

power-continuous energy transduction

Ambiguity of Series and Parallel for Mechanical Systems

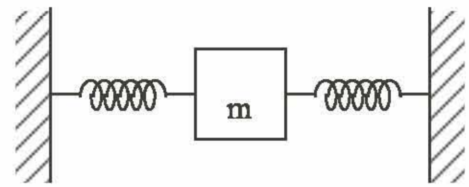
Electrical elements in parallel have the same voltage. Electrical elements in series have the same current.

A: These two springs are apparently in parallel.



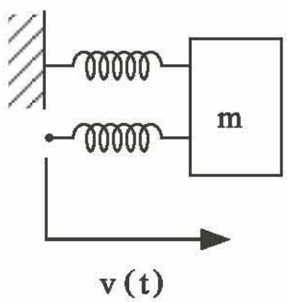
Though A & B are visually different, in both cases knowing the displacement of one spring determines the displacement of the other.

B: These two springs are apparently in series.



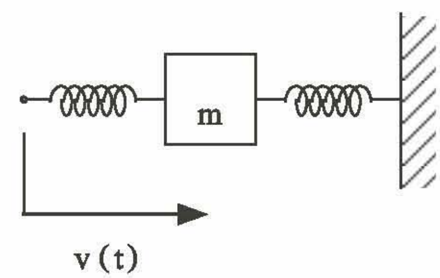
Though A & C are visually similar, the relation between spring displacements is different: in C the displacements are independent.

Though B & D are visually similar, the relation between spring displacements is different: in D the displacements are independent.



C: These two springs are apparently in parallel.

Though C & D are visually different, in both cases the displacement of one spring is independent of the other.



D: These two springs are apparently in series.

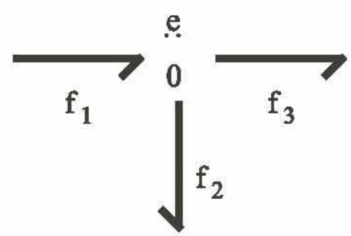
Some Bond Graph Embellishments

Parameters of ideal linear elements may be written adjacent to the element symbol.

ideal, linear mechanical spring

ideal, linear electrical inductor

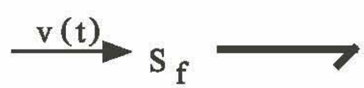
Their common variables may be written adjacent to zero- or one-junctions.



Variables of source elements may be written adjacent to the element symbol.

mechanical velocity source

A line with a full arrowhead may denote "signal" transmission (without power exchange).



USE SPARINGLY AND CAREFULLY!