CIRCULATORY AND CARDIAC BIOPHYSICS

CIRCULATORY SYSTEM

A. Function:

Maintenance of environmental parameters of cells
"Steady state"
Transport:
- Gases
- Metabolites
- Hormones, signal transmitters
- Immunoglobulins
- Heat

B. Hemodynamic requirements:

Slow (low flow rate)
Steady (no fluctuations)
Unidirectional

C. The vascular system is a closed vessel system returning into itself

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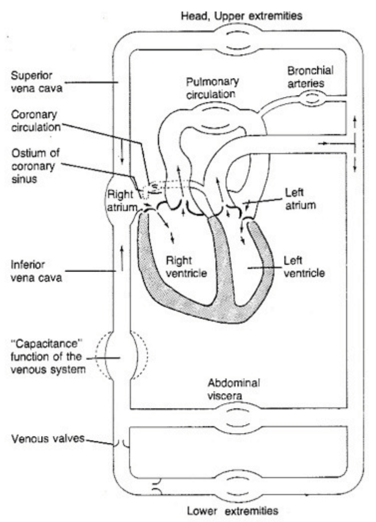
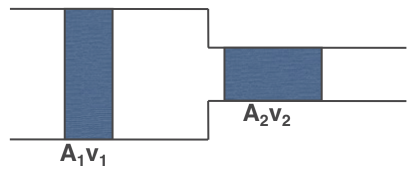


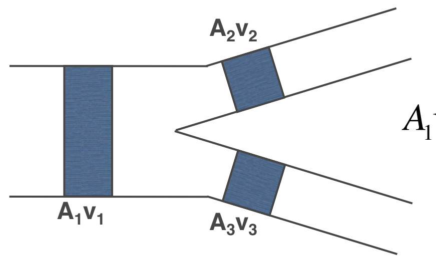
Fluid flow in vessel

Continuity equation – reminder



$$A_1v_1 = A_2v_2 = const$$

A=cross-sectional area
v=flow rate



$$A_1v_1 = A_\Sigma(v)_{average} = const$$

A_Σ=total cross-sectional area

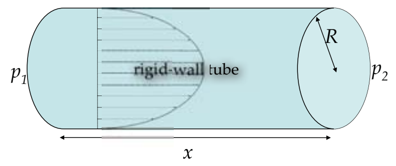
THERMODYNAMIC CURRENTS

- Natural processes are rarely reversible.
- If there are inequalities in the intensive variables at different locations within the system, thermodynamic currents arise.
- Thermodynamic currents aim at the restoration of equilibrium.

Thermodynamic current	Relevant intensive variable (its difference maintains current)	Current density	Physical law
Heat flow	Temperature (T)	$J_E = -\lambda \frac{\Delta T}{\Delta x}$	Fourier
Volumetric flow	Pressure (p)	$J_V = -\frac{R^2}{8\eta}\frac{\Delta p}{\Delta x}$	Hagen-Poiseuille
Electric current	Electric potential (ϕ)	$J_Q = -\frac{1}{\rho}\frac{\Delta\varphi}{\Delta x}$	Ohm
Material transport (diffusion)	Chemical potential (μ)	$J_n = -D\frac{\Delta c}{\Delta x}$	Fick

VOLUME FLOW

Thermodynamic current	Relevant intensive variable (its difference maintains current)	Current density	Physical law
Volumetric flow	Pressure (p)	$J_V = -\frac{R^2}{8\eta}\frac{\Delta p}{\Delta x}$	Hagen-Poiseuille



V = volume
t = time
R = tube radius
η = viscosity
p = pressure
x = tube length
($\Delta p/\Delta x$ = pressure gradient, maintained by p_1-p_2)
A = cross-sectional area of tube
J_V = flow intensity

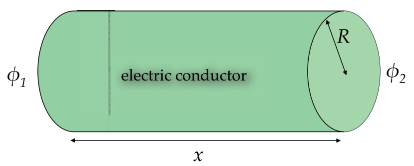
$$\frac{V}{t} = \frac{R^4\pi}{8\eta}\frac{\Delta p}{\Delta x}$$

$$A = R^2\pi$$

$$J_V = \frac{V}{tA} = \frac{R^2}{8\eta}\frac{\Delta p}{\Delta x}$$

ELECTRIC CURRENT

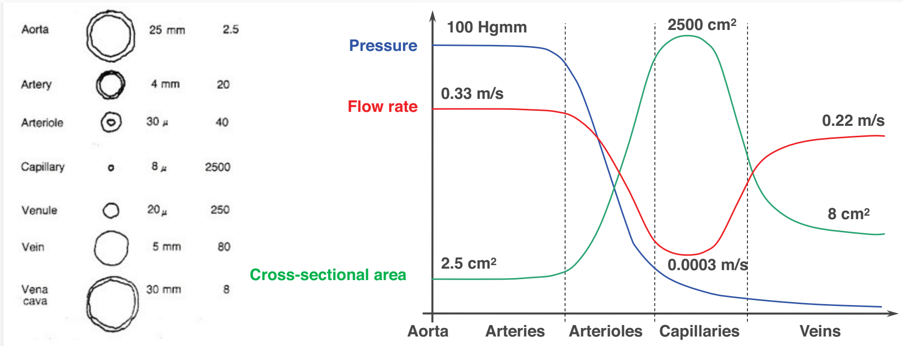
Thermodynamic current	Relevant intensive variable (its difference maintains current)	Current density	Physical law
Electric current	Electric potential (ϕ)	$J_Q = -\frac{1}{\rho}\frac{\Delta\varphi}{\Delta x}$	Ohm



q = electric charge
t = time
R = tube radius
ϕ = electric potential
x = length of conductor
($\Delta\phi/\Delta x$ = potential gradient (voltage), maintained by ϕ_1-ϕ_2)
A = cross-sectional area of tube
J_Q = electric current

$$\frac{q}{tA} = J_Q = -\frac{1}{\rho}\frac{\Delta\varphi}{\Delta x}$$

Structure and physical properties of the vascular system

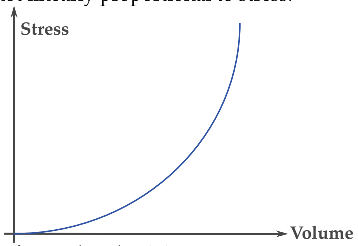


Pressure> pressure that sustains flow, *"blood pressure"*.
Reason of **pressure drop**: flow resistance; most of energy is converted to heat.
Flow rate and total **cross-sectional area** change inversely (based on equation of continuity, Av=constant).
Flow rate typically does not exceed the **critical** (see Reynolds number),and flow remains laminar. (But: behind aortic valve, constricted vessels, low-viscosity conditions, Korotkoff sound).
Arterioles (vessels containing smooth muscle, under vegetative innervation) are pressure-regulators: *"resistance vessels."*
Most of blood volume in veins: *"capacitance vessels."*

Blood vessels as elastic tubes

Non-liear elasticity

Strain is not linearly proportional to stress.



Determinants of vascular elasticity:

Elastin
Collagen
Smooth muscle

Implications of vascular easticity:

Storage of potential (elastic) energy
Dampening of pressure pulses
Constant flow rate

Wall tension and bood pressure

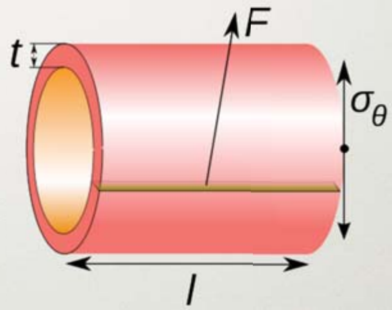
Circumferential stress (σ_θ) - (Young-Laplace - equation)

$$\sigma_\theta = \frac{P \cdot r}{t}$$

P = blood pressure
r = radius of tube
t = wall thickness

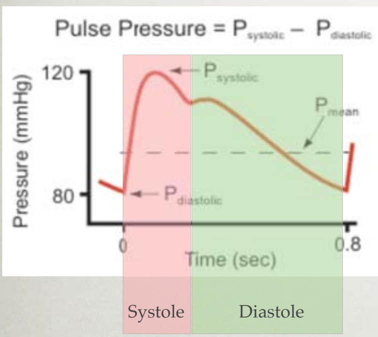
$$\sigma_\theta = \frac{F}{t \cdot l}$$

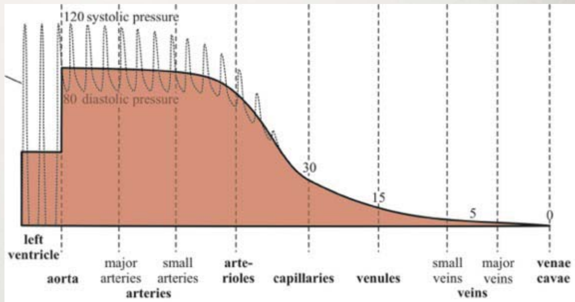
F = force
l = tube length



Wall tension or circumferential stress is the average force exerted circumferentially (perpendicular to both the axis and the radius) in the cylinder wall.

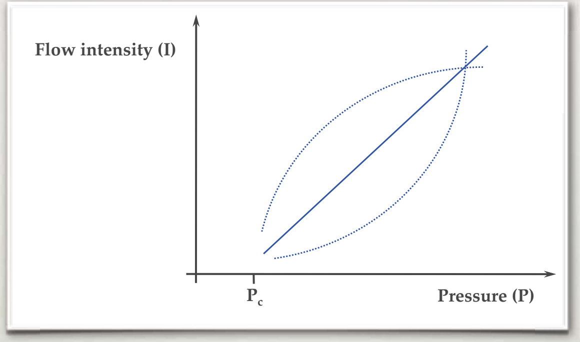
Dynamic pressure-changes in the arterial system





Because of vessel wall elasticity, pressure fluctuations are dampened.

Relationship between flow intesity and pressure



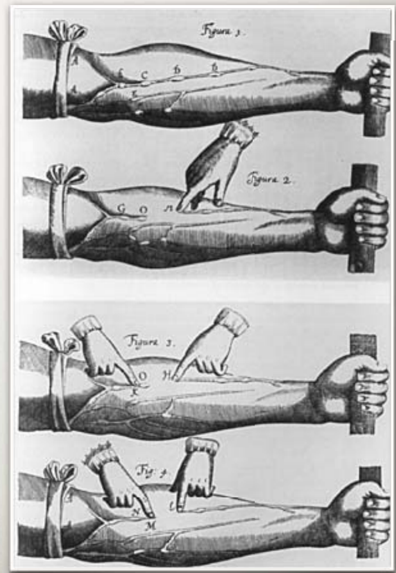
N.B.:

-The curves intersect the pressure axis at values greater than 0 (critical closing pressure, P_c).

Auxiliary factors of circulation

1. **Arterial elasticity**
   (storage of potential energy)
2. **Venous valves** (Harvey's experiment)
   "On the Circulation of the Blood" (1628).

3. **Muscle action**
4. **Negative intrathoracic pressure**
5. "Up-and-down" movement
   of **atrioventricular plane**



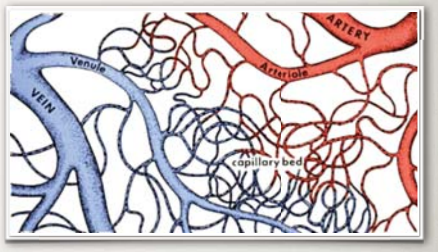
Harvey's experiment

Capillary circulation, fluid exchange

1. Capillaries:
Length: 400-700 μm
Diameter: 0.5 μm

2. Open state depends on function
Number of open caillaries in muscle:
Rest - 5/mm^2
Activity - 200/mm^2

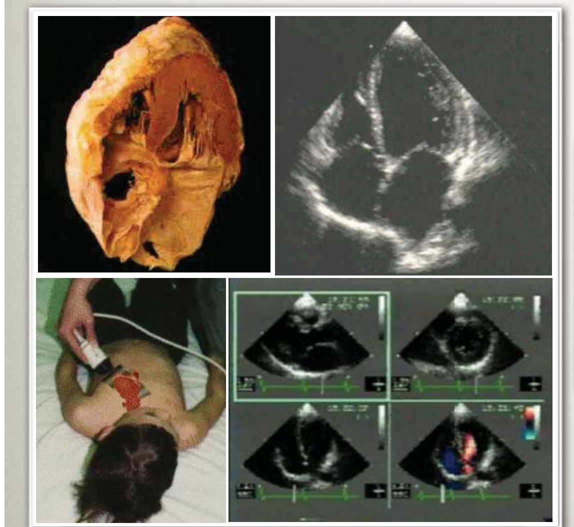
3. Capillary fluid exchange
fluid movement between bloof plasma and interstitium
driven by: difference in blood pressure and colloid osmotic pressure
Colloid osmotic (oncotic) pressure:
osmotic pressure caused by the presence of colloidal proteins (2.6 kPa)



	Arterioles	Capillaries	Venules
Bood pressure	4.0 kPa	2.6 kPa	1.3 kPa
Colloid osmotic pressure	2.6 kPa	2.6 kPa	2.6 kPa

CARDIAC BIOPHYSICS

Heart:
Pump of the circulatory system

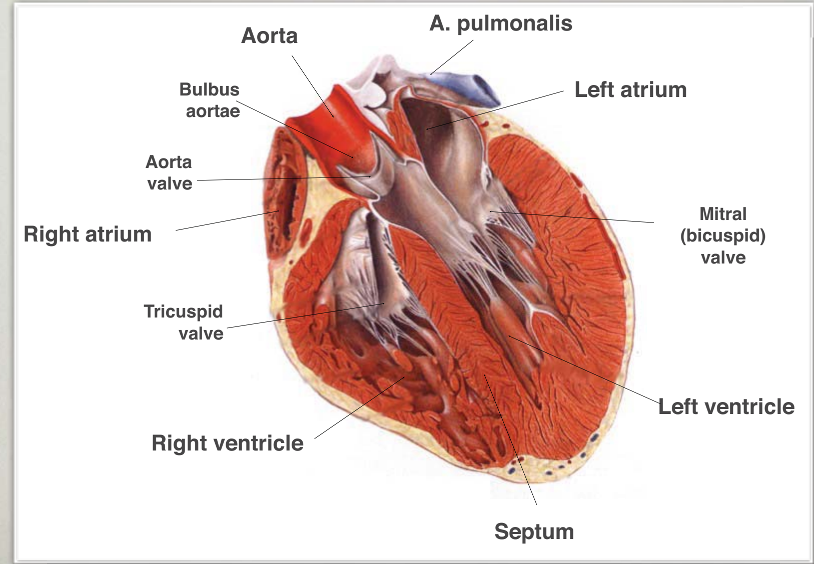


	Number of contractions	Expelled blood volume
1 min	~70	~6 l
1 day	~100.000	~8600 l
Life (70 yrs)	~2.5 x 10^9	~220 x 10^6 l

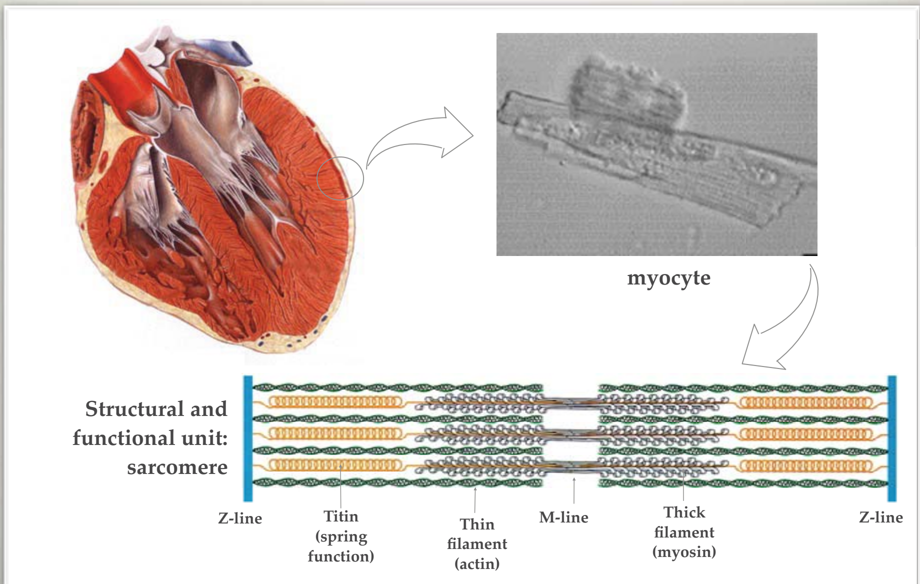
Cardiac biophysics

1. Structure of the heart
2. Coordinated contraction
3. The cardiac cycle
4. Work of the heart

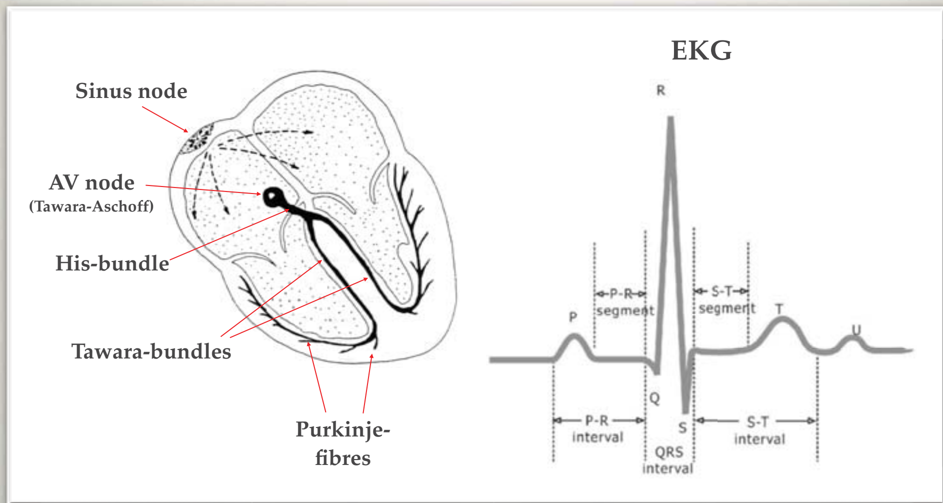
Structure of the human heart



Functional structure of the heart

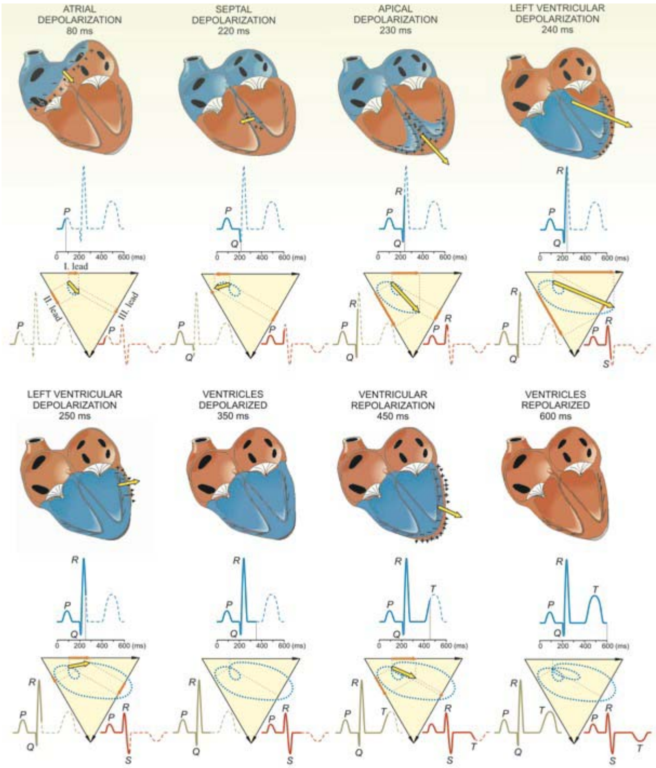


Activation of coordinated contractions



EKG:

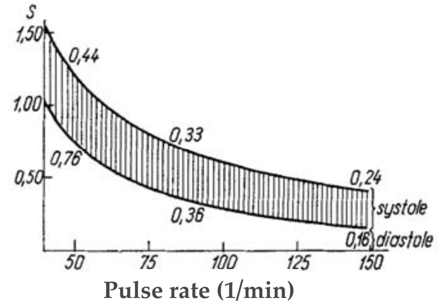
Vectorial projections (according to leads) of the resultant dipole (integral vector) that changes in time and space during myocardial depolarization and repolarization.



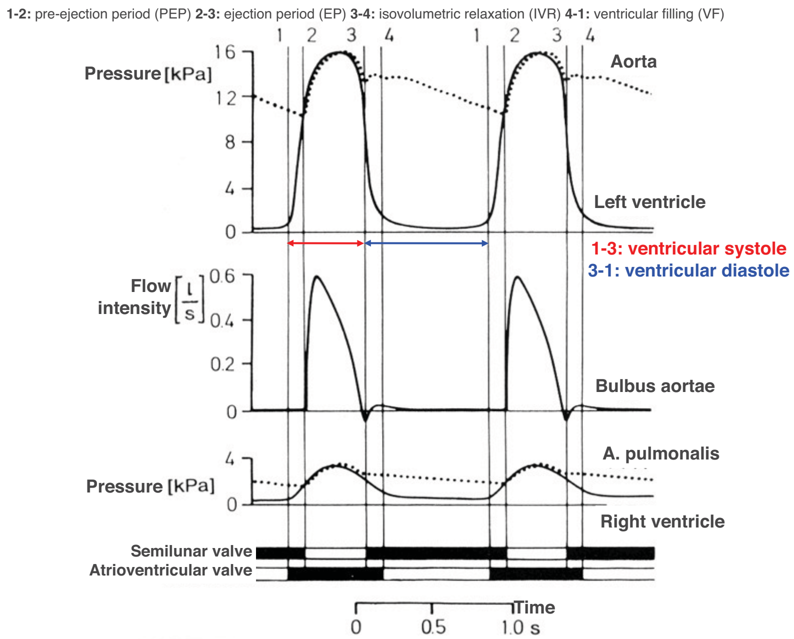
The cardiac cycle

Contraction (systole) - relaxation (diastole) cycle of the heart

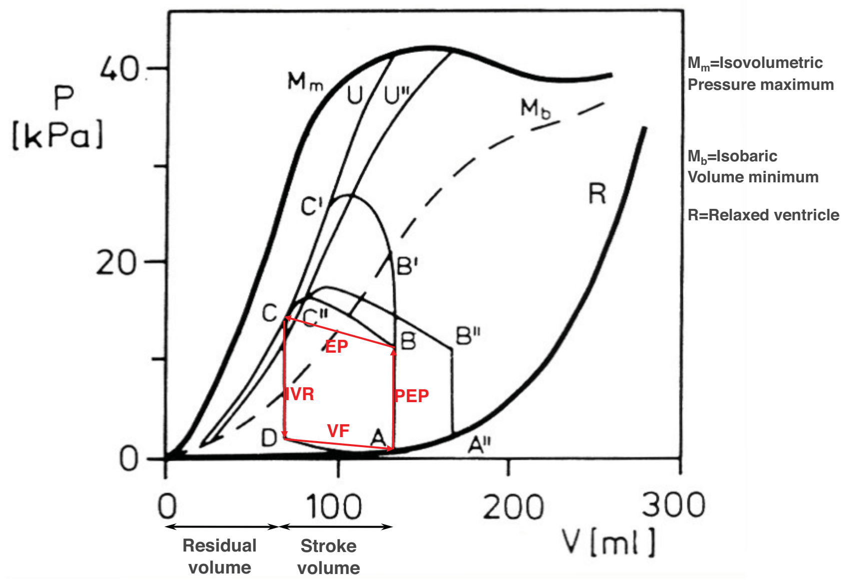
	systole	diastole
atrium	0,1 s	0,7 s
ventricle	0,3 s	0,5 s



Events of the cardiac cycle

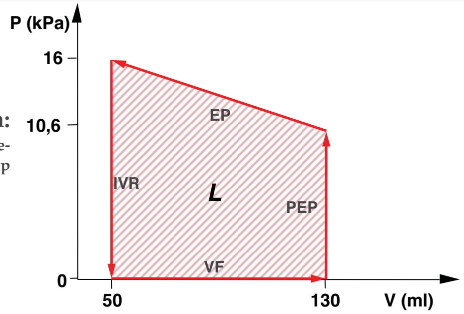


Pressure-volume diagram of left ventricle



Work of the heart
(work of the left ventricle)

Indicator diagram:
Simplified pressure-volume relationship



$$L = p\Delta V + \frac{1}{2}mv^2$$

pΔV=static (volumetric) component
1/2mv²=dynamic component
p=pressure
ΔV=**stroke volume**

$$13{,}3\cdot 10^3\,N/m^2 \times 0{,}08\cdot 10^{-3}\,m^3 + \frac{1}{2}0{,}08kg \times (1m/s)^2 = 1{,}06Nm + 0{,}04Nm = 1{,}1J$$