Moduli at finite temperature

Michael Ratz

15th Rencontres du Vietnam Cosmology 2019

Based on:

- W. Buchmüller, K. Hamaguchi, O. Lebedev & M.R. Nucl. Phys. B699, 292-308 (2004)
- B. Lillard, M.R., T. Tait & S. Trojanowski JCAP 1807 no. 07, 056 (2018)

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moduli (SM singlets)

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purpose of this talk:

discuss moduli in the hot early universe

Basic assumptions & results

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- well–known gravitino problem
- moduli problem more model dependent but also typically more severe

Moduli problems

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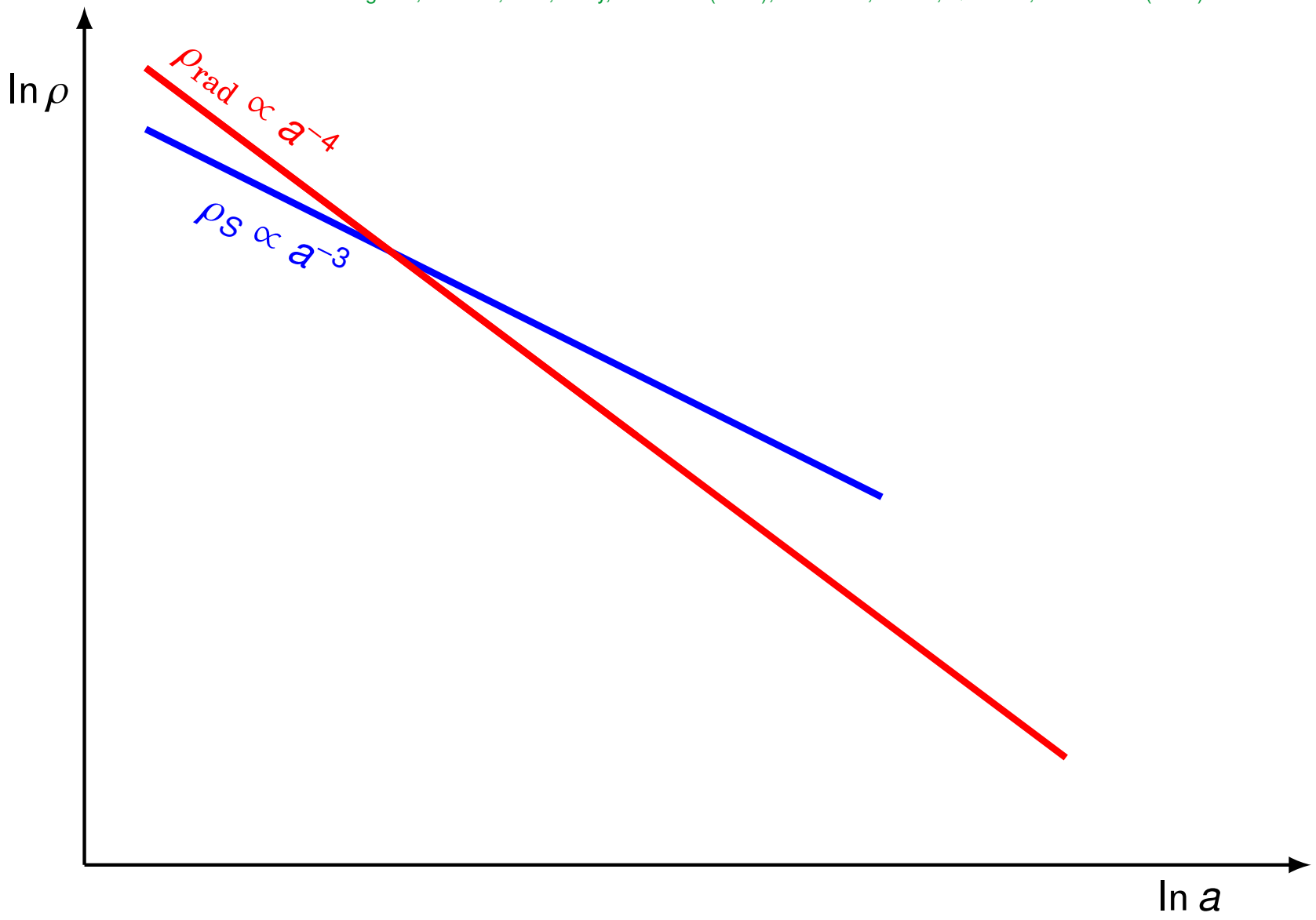

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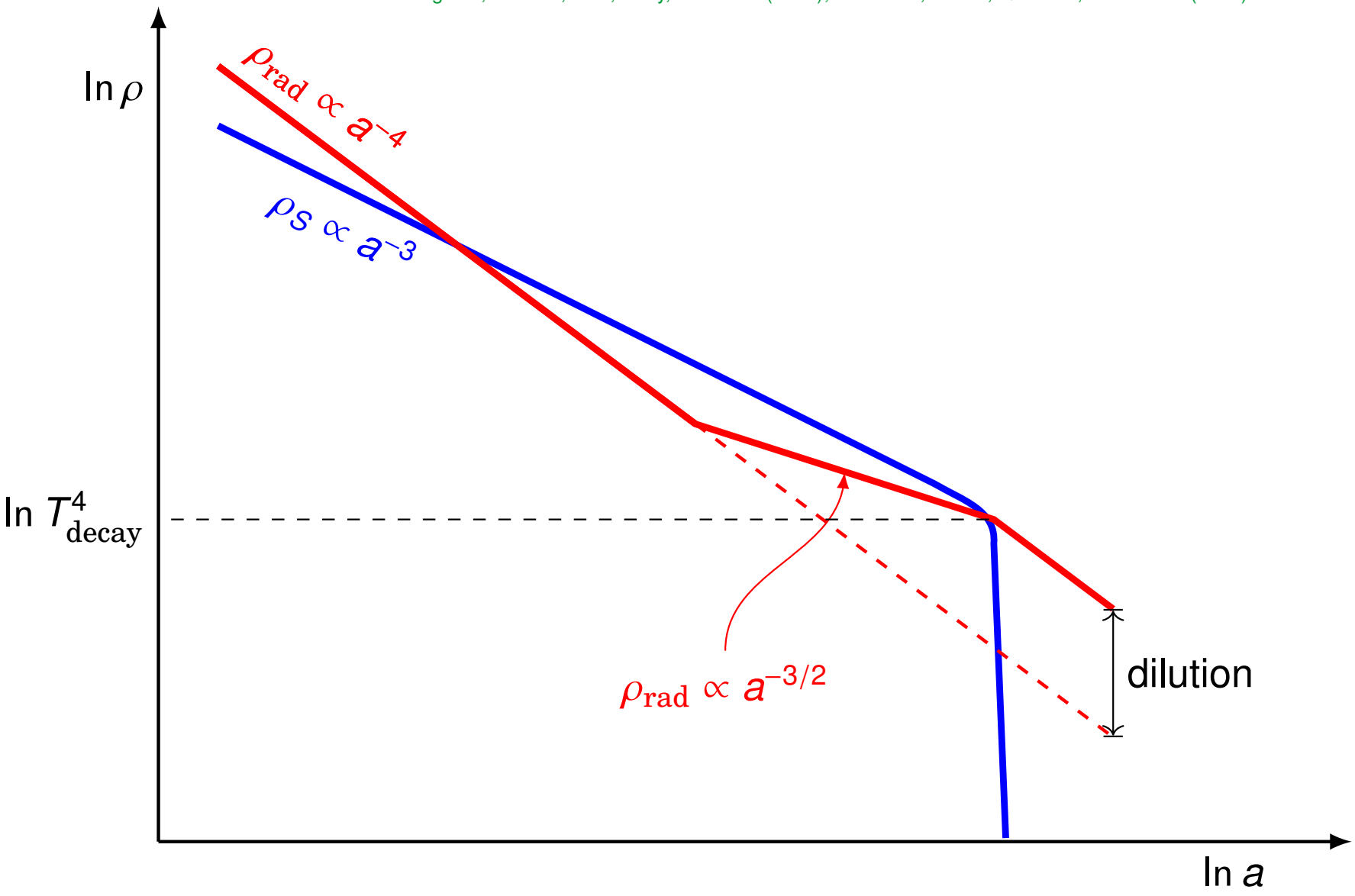

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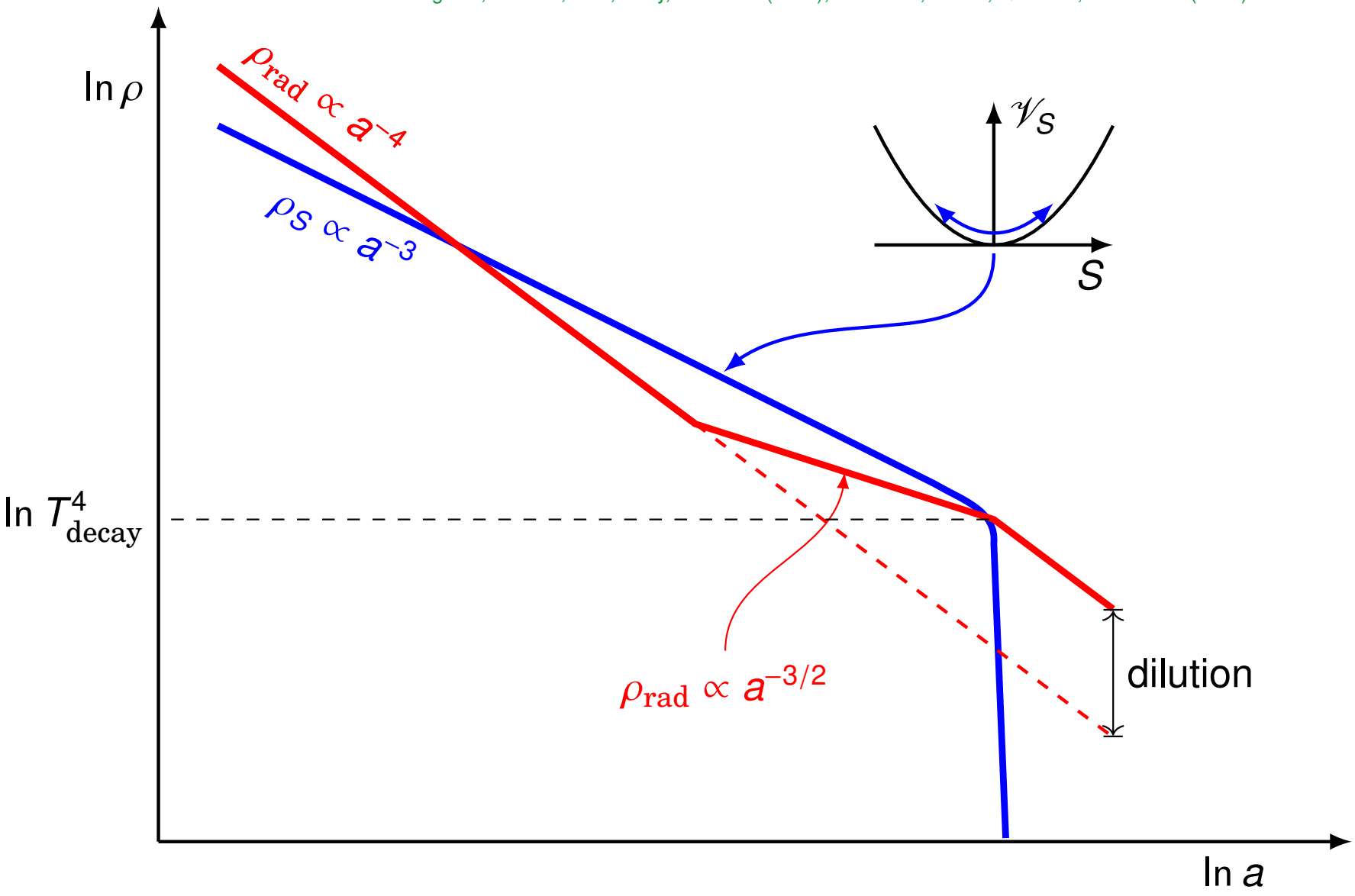

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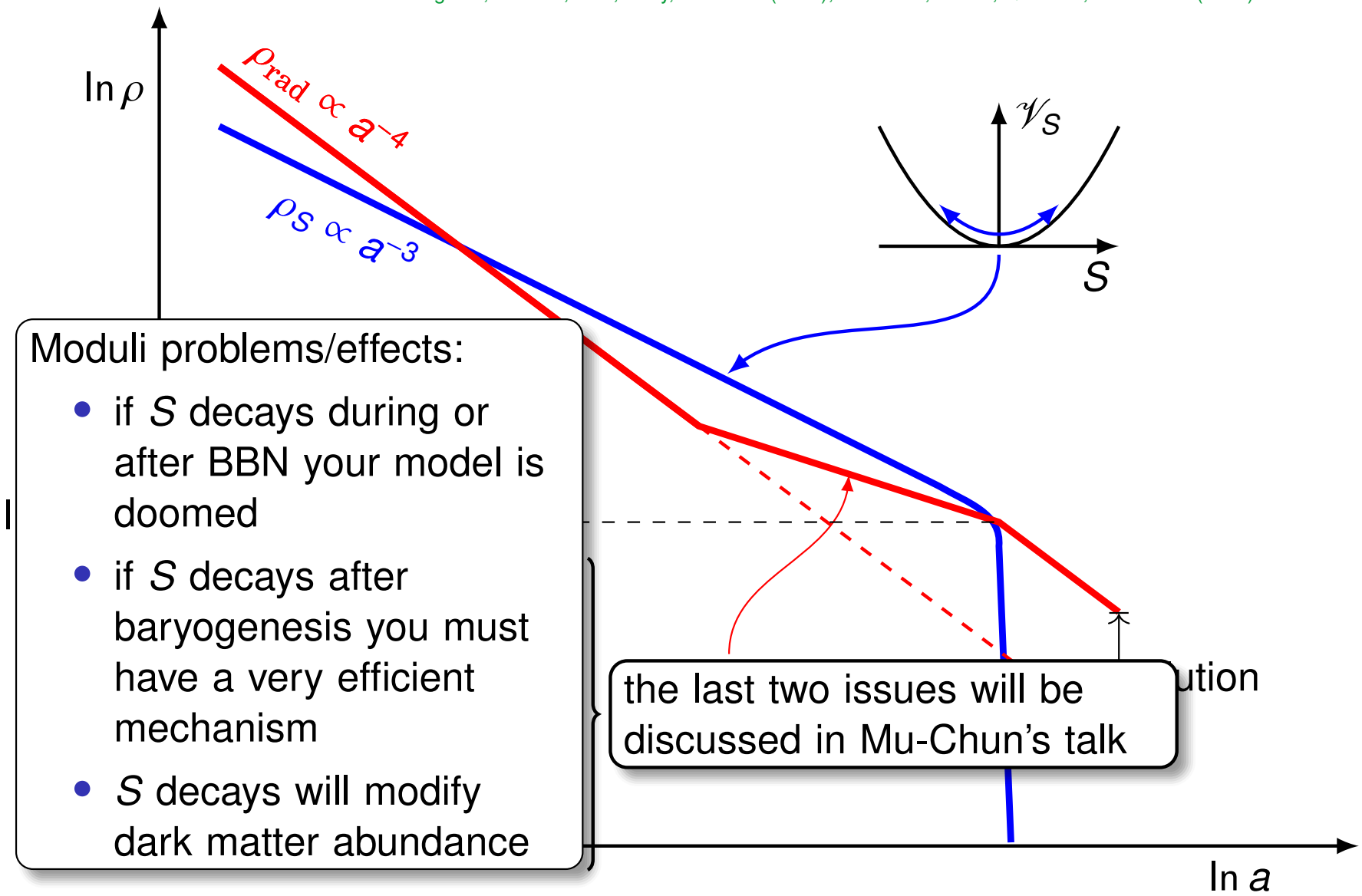

Moduli problems/effects:

- if S decays during or after BBN your model is doomed
- if S decays after baryogenesis you must have a very efficient mechanism
- S decays will modify dark matter abundance

the last two issues will be discussed in Mu-Chun's talk

Main focus of this talk

- will show that moduli move in such a way that couplings *decrease*

$$g \xrightarrow{T\to\text{large}} 0 \quad \text{and} \quad y \xrightarrow{T\to\text{large}} 0$$

temperature

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$$g \xrightarrow{T\to\text{large}} 0 \quad \text{and} \quad y \xrightarrow{T\to\text{large}} 0$$

- substantial change of couplings when

$$T \sim T_{\text{crit}} = \sqrt{\Lambda\, m_S}$$

Thermal potential for moduli

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free energy

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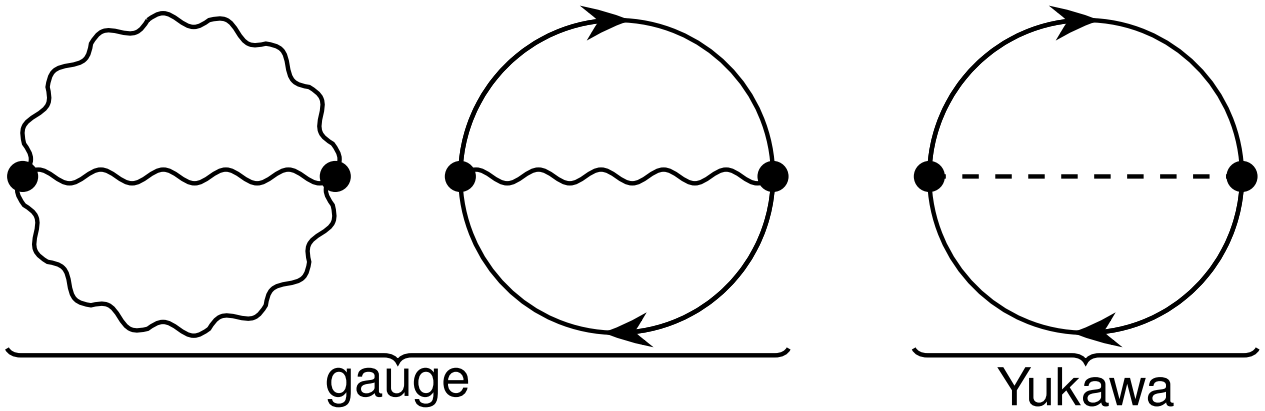

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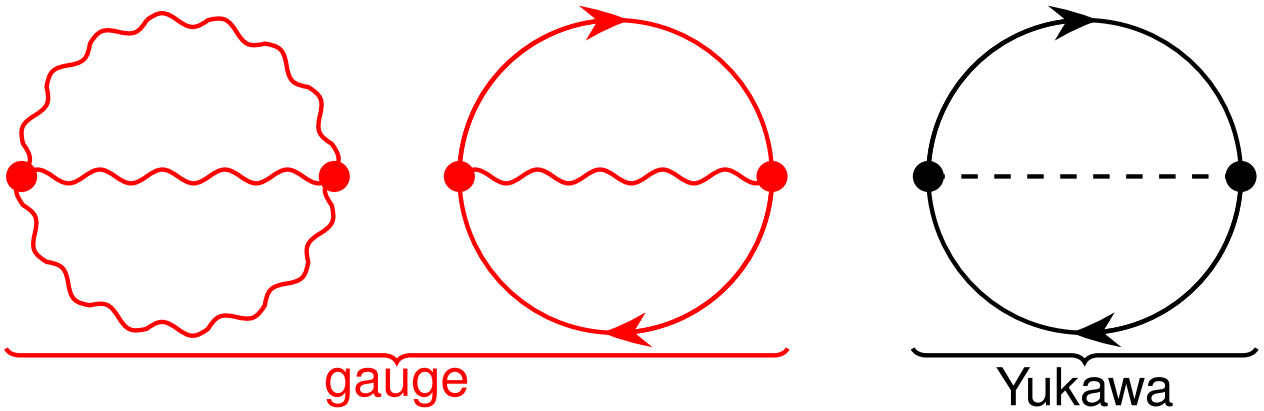

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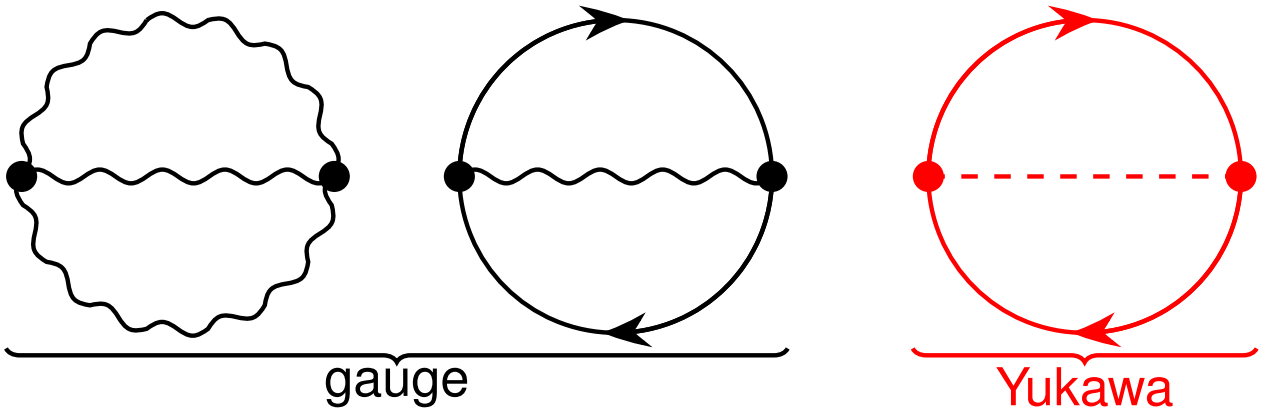

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$$\alpha_2 = \frac{3}{196}(N_C^2 - 1)(N_C + 3N_F) \text{ for } \mathrm{SU}(N_C) \text{ w/ } N_F \text{ fundamentals}$$

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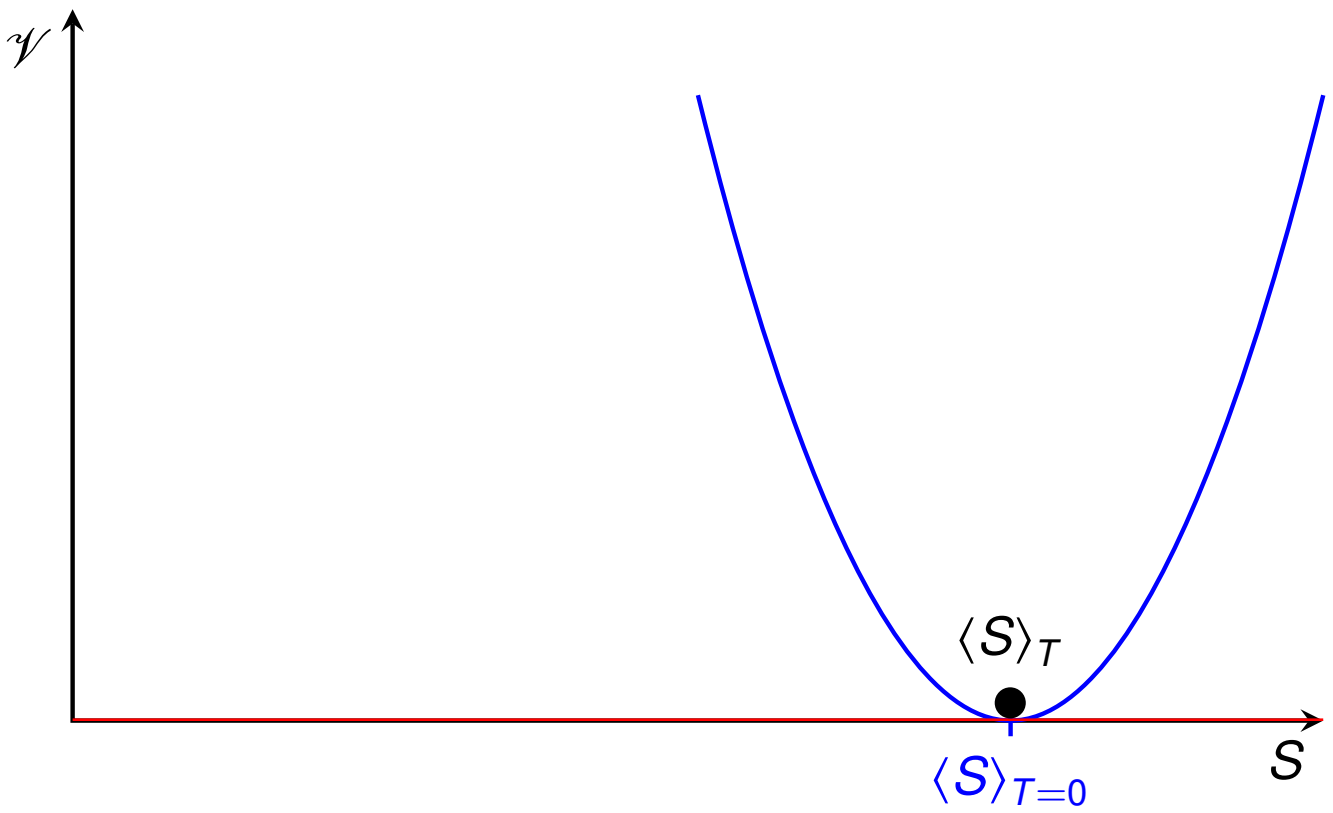
- crucial: signs are *positive*

➥ free energy gets minimized for *smaller* couplings y and g

Thermal moduli potential (cartoon)



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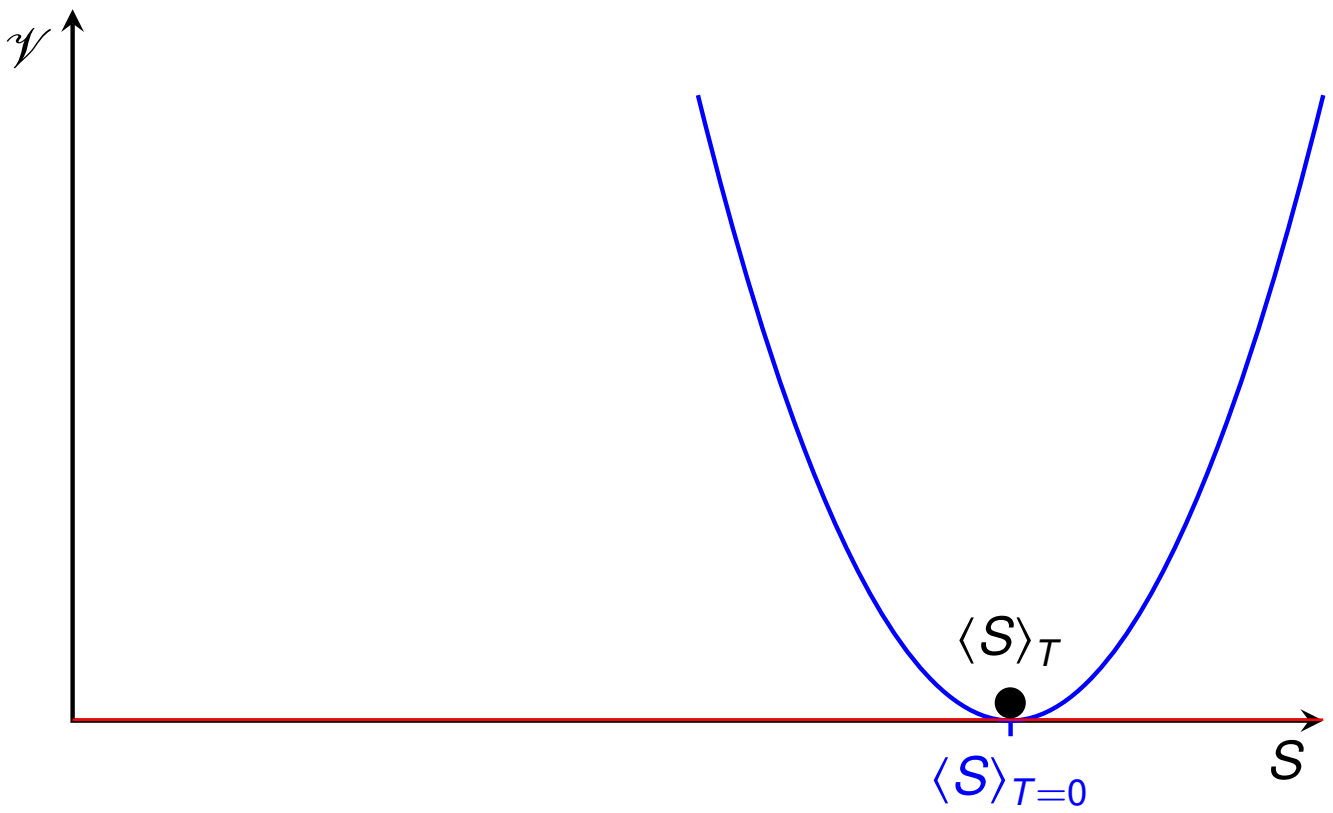

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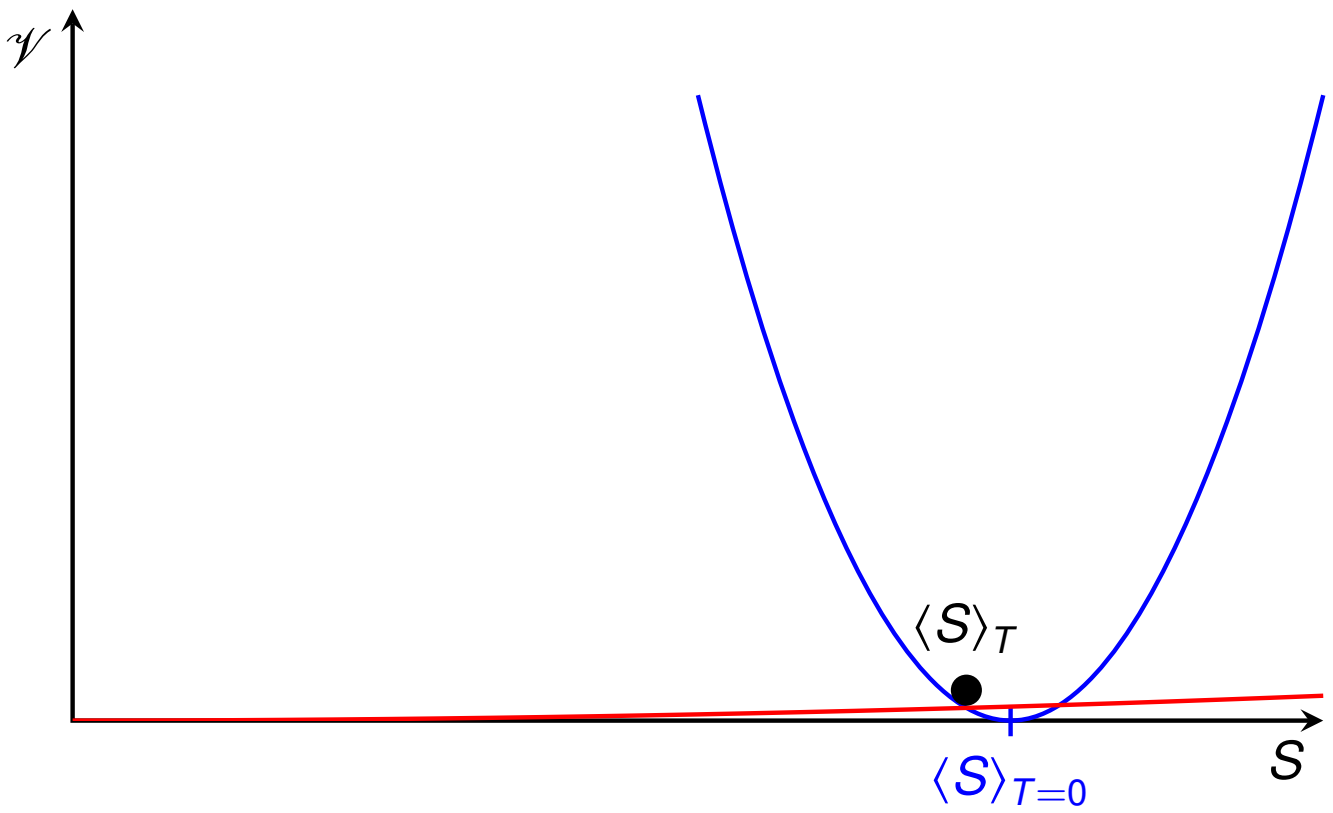

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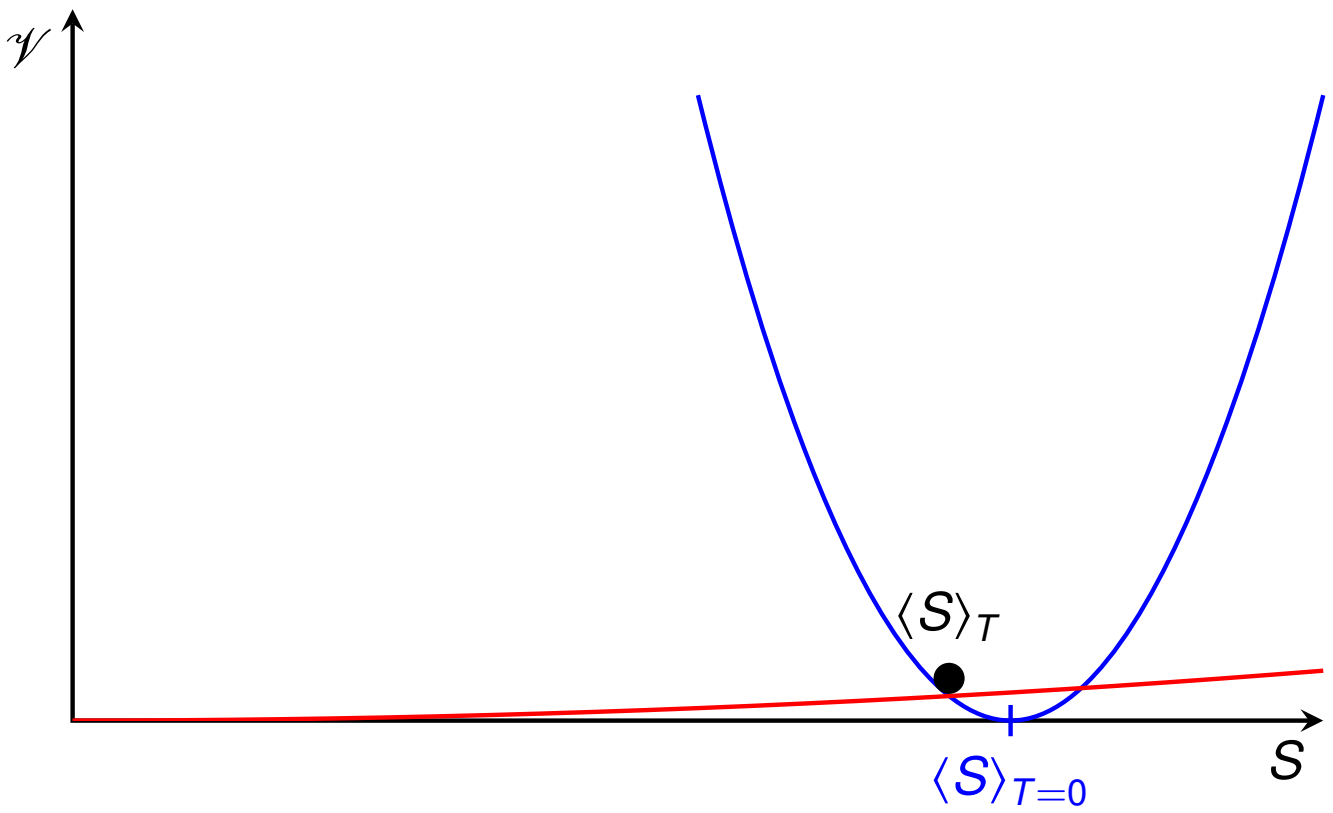

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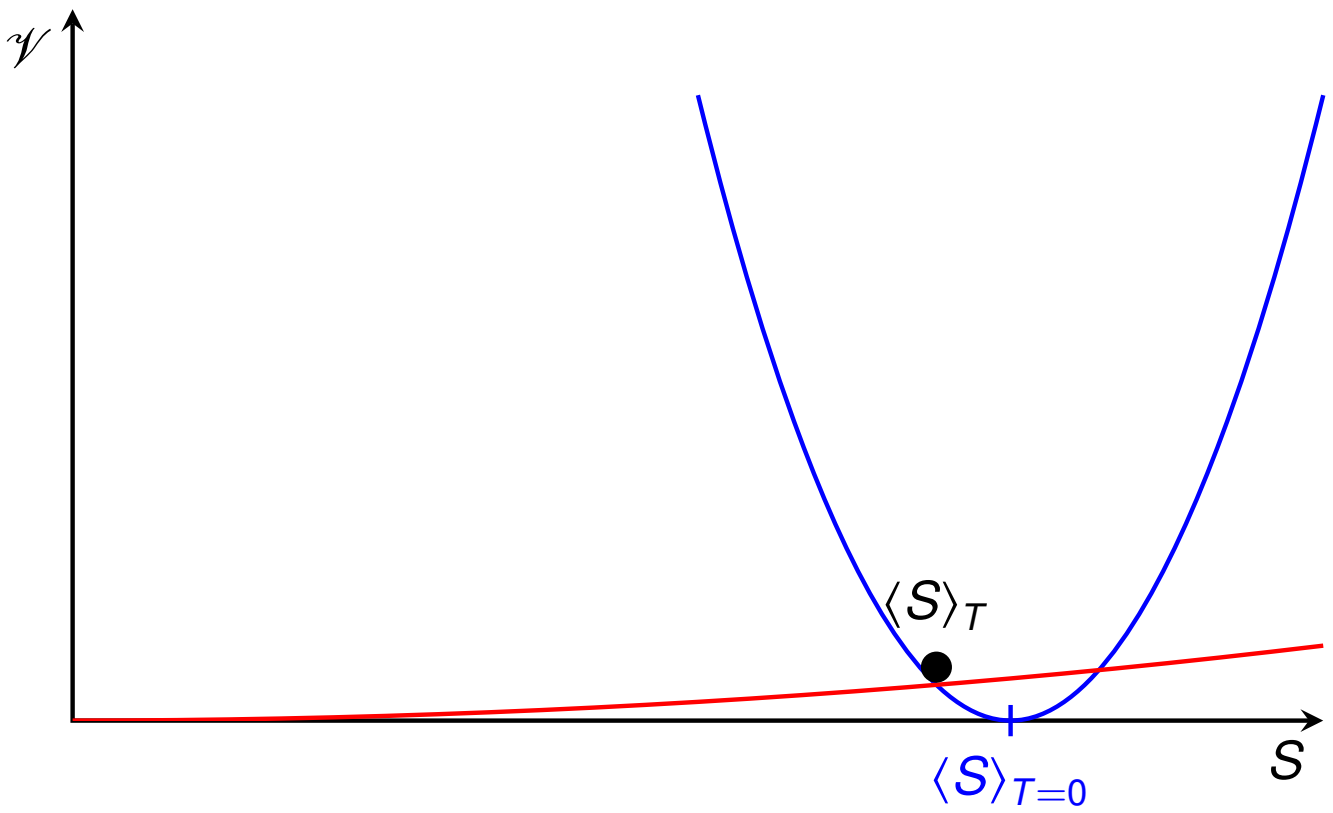

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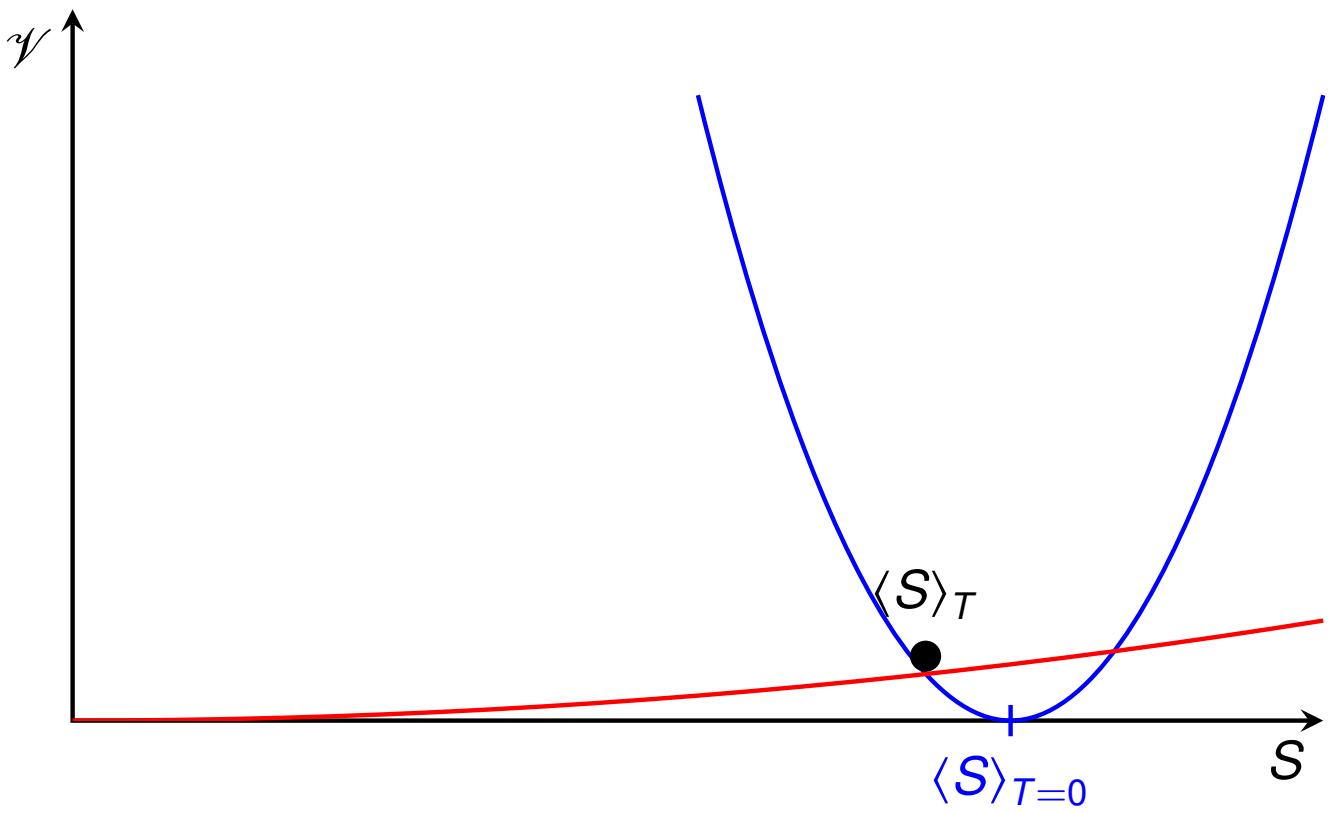

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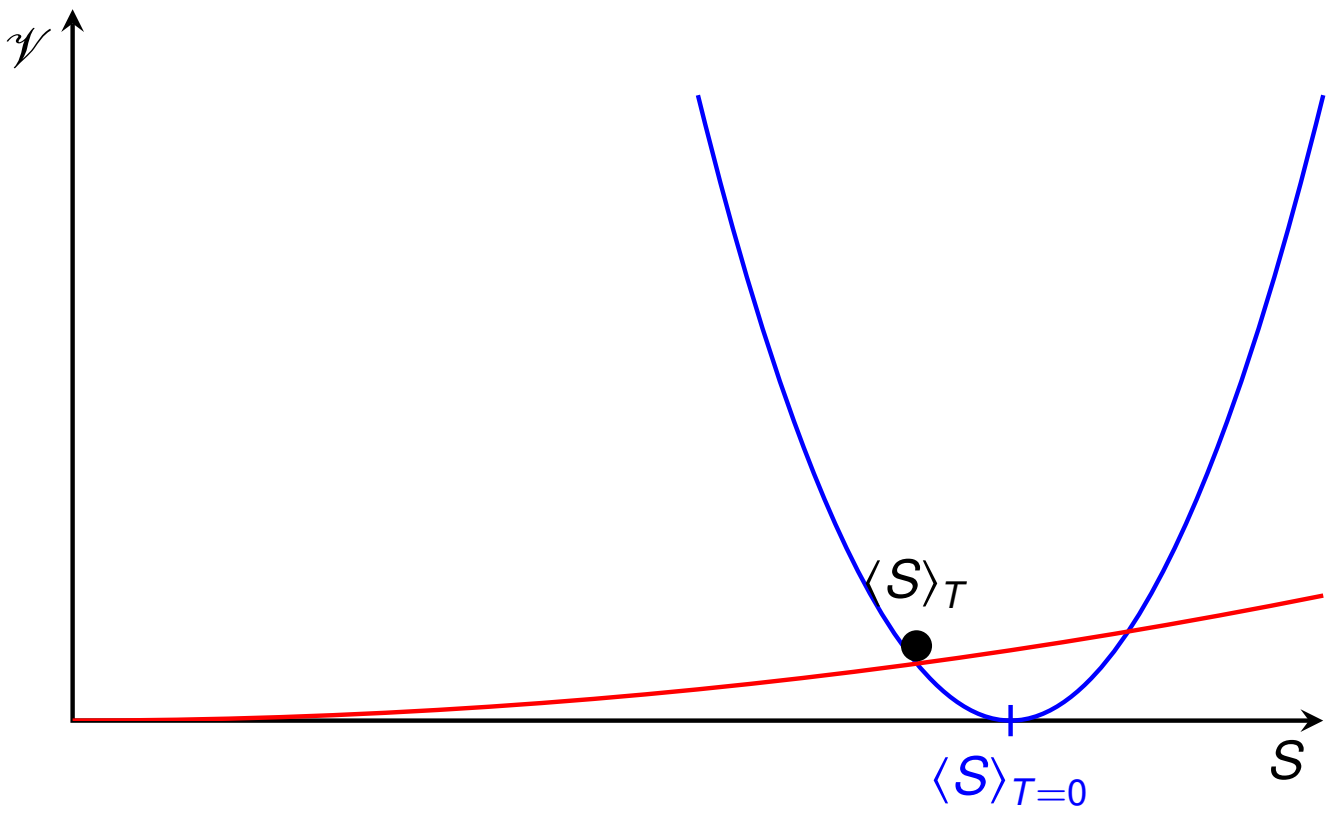

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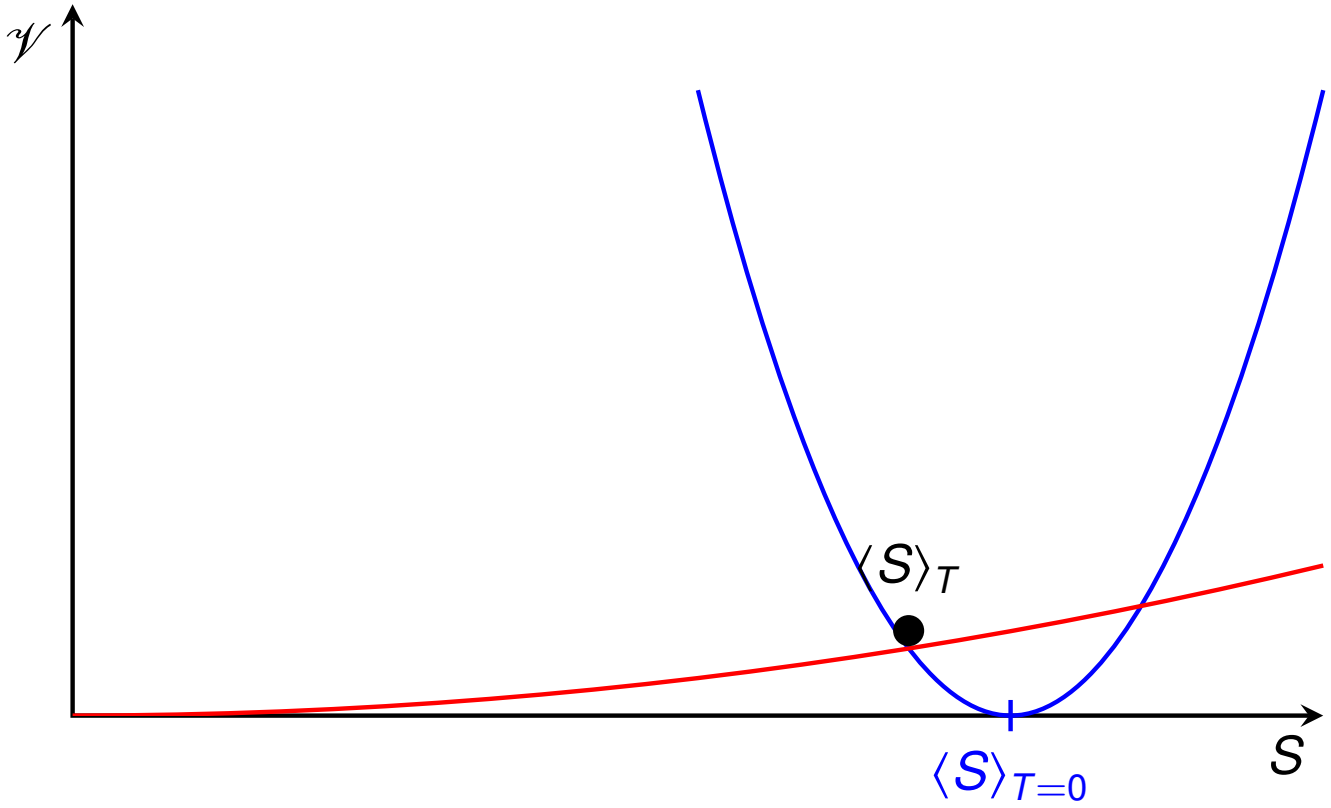

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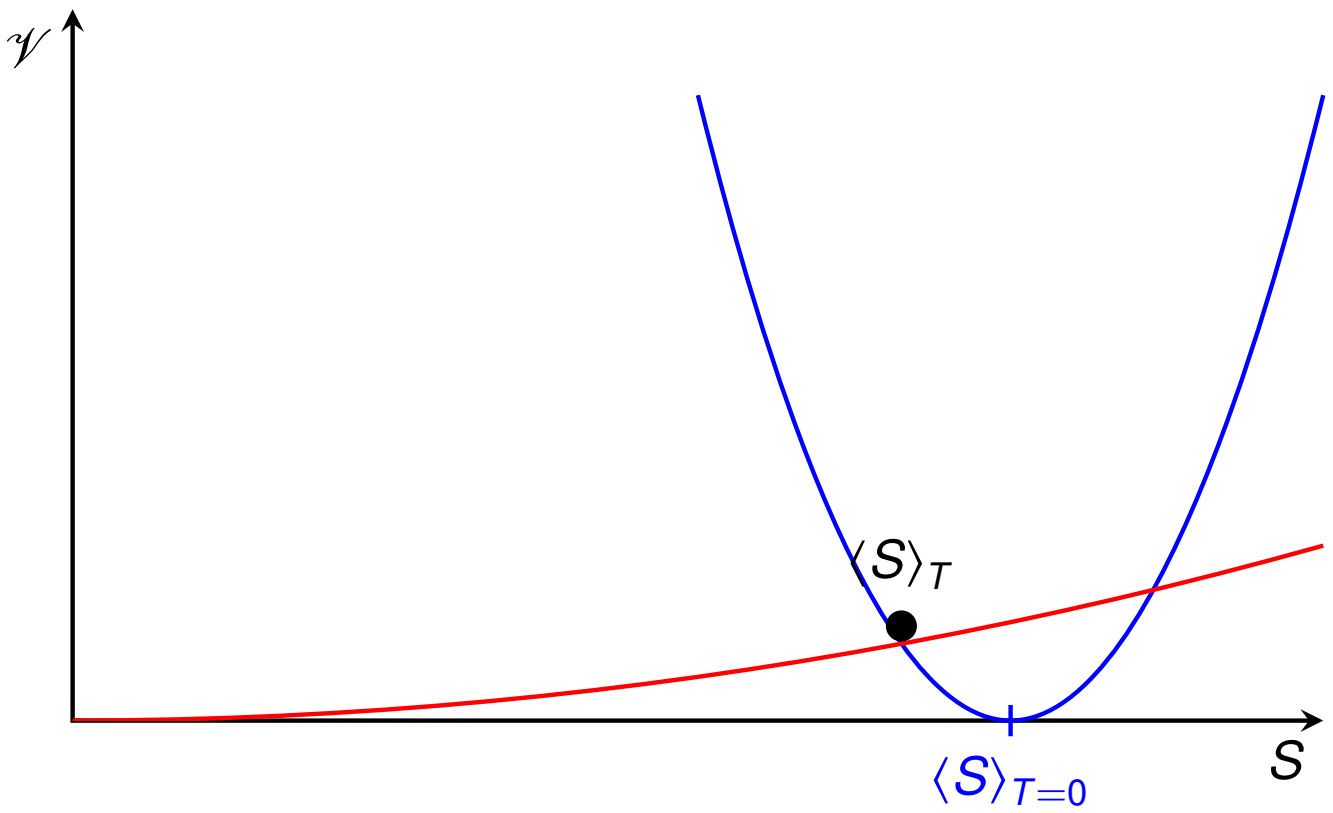

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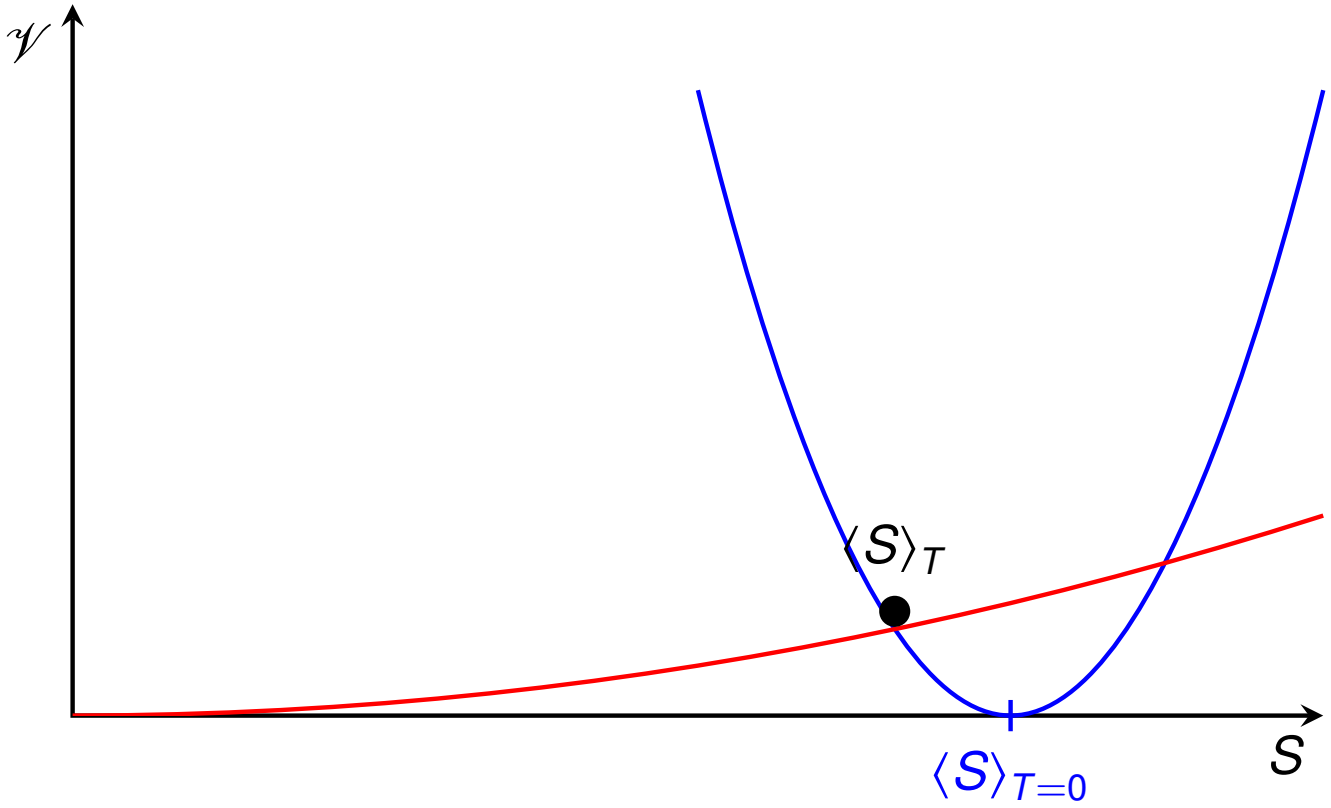

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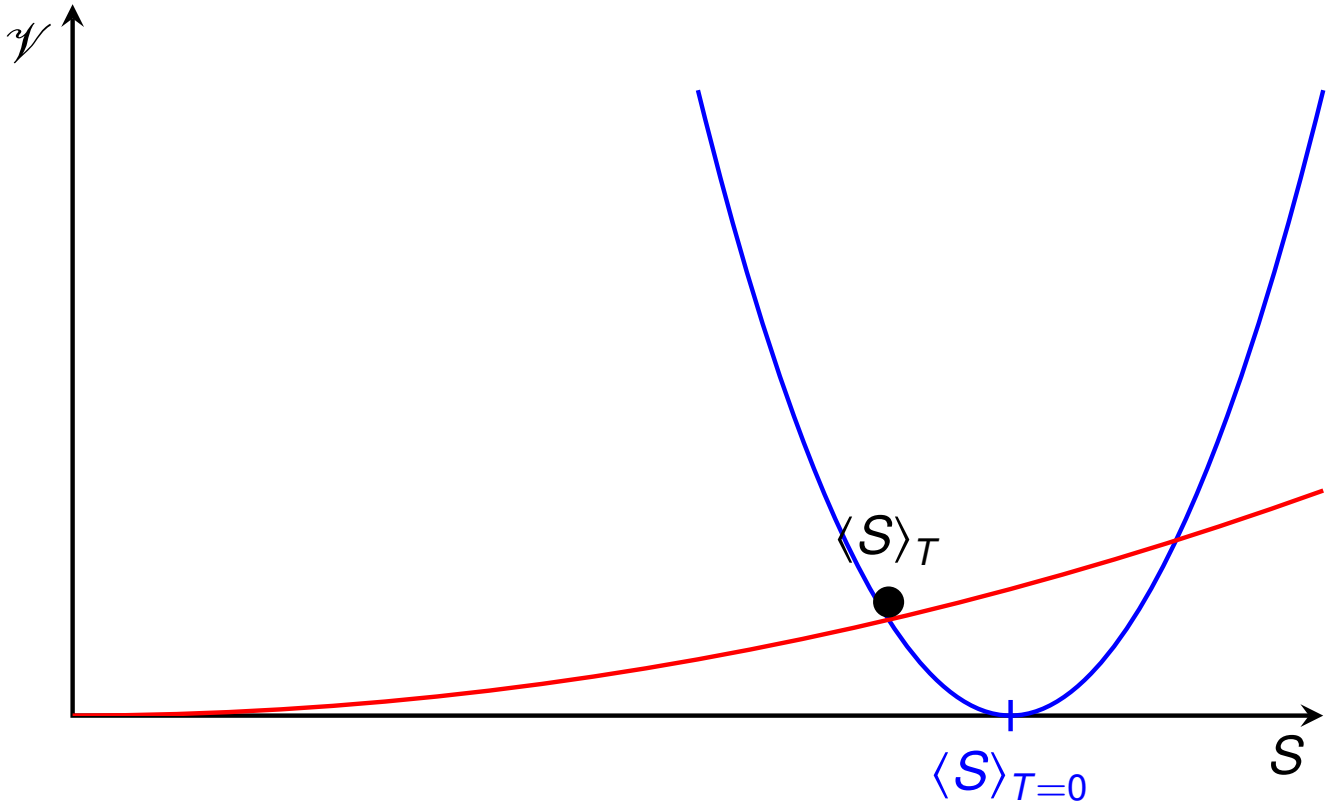

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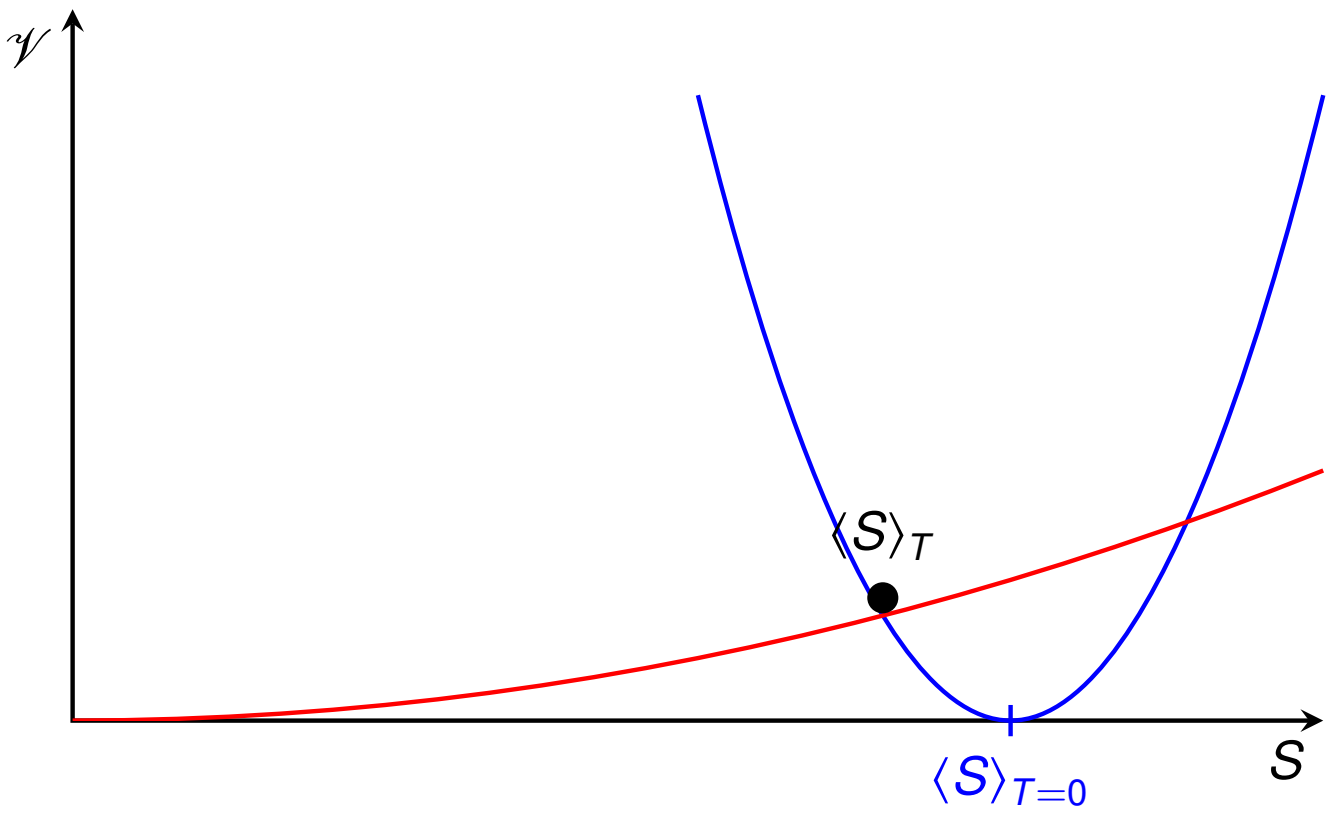

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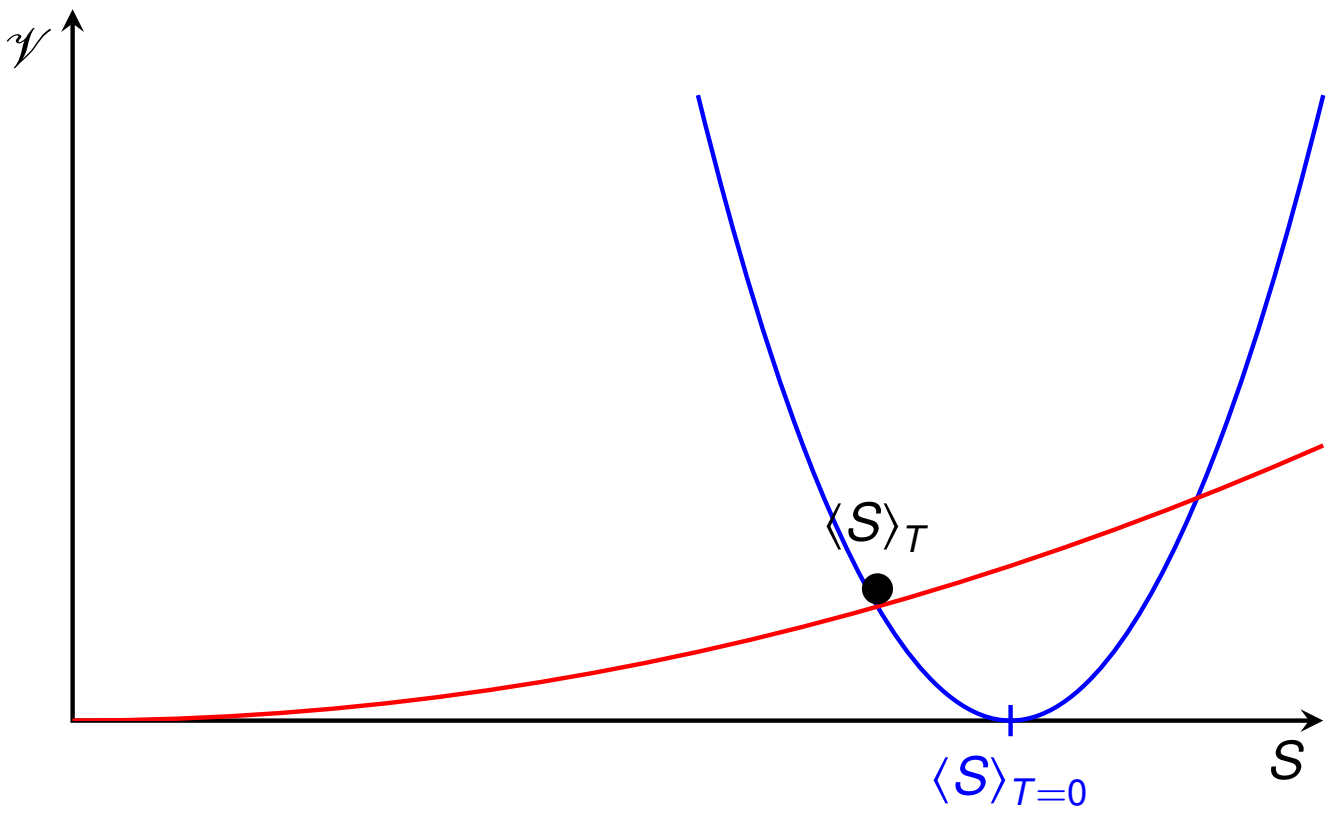

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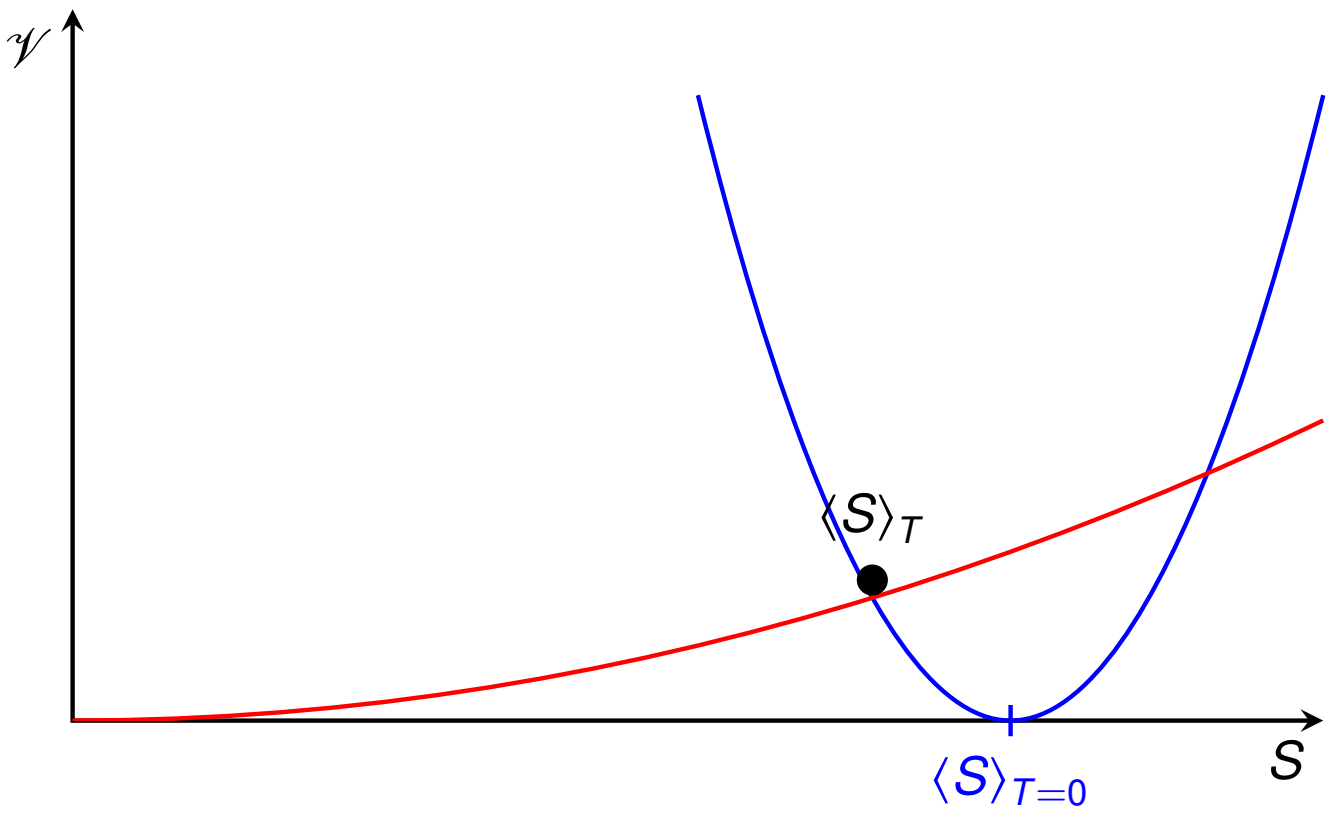

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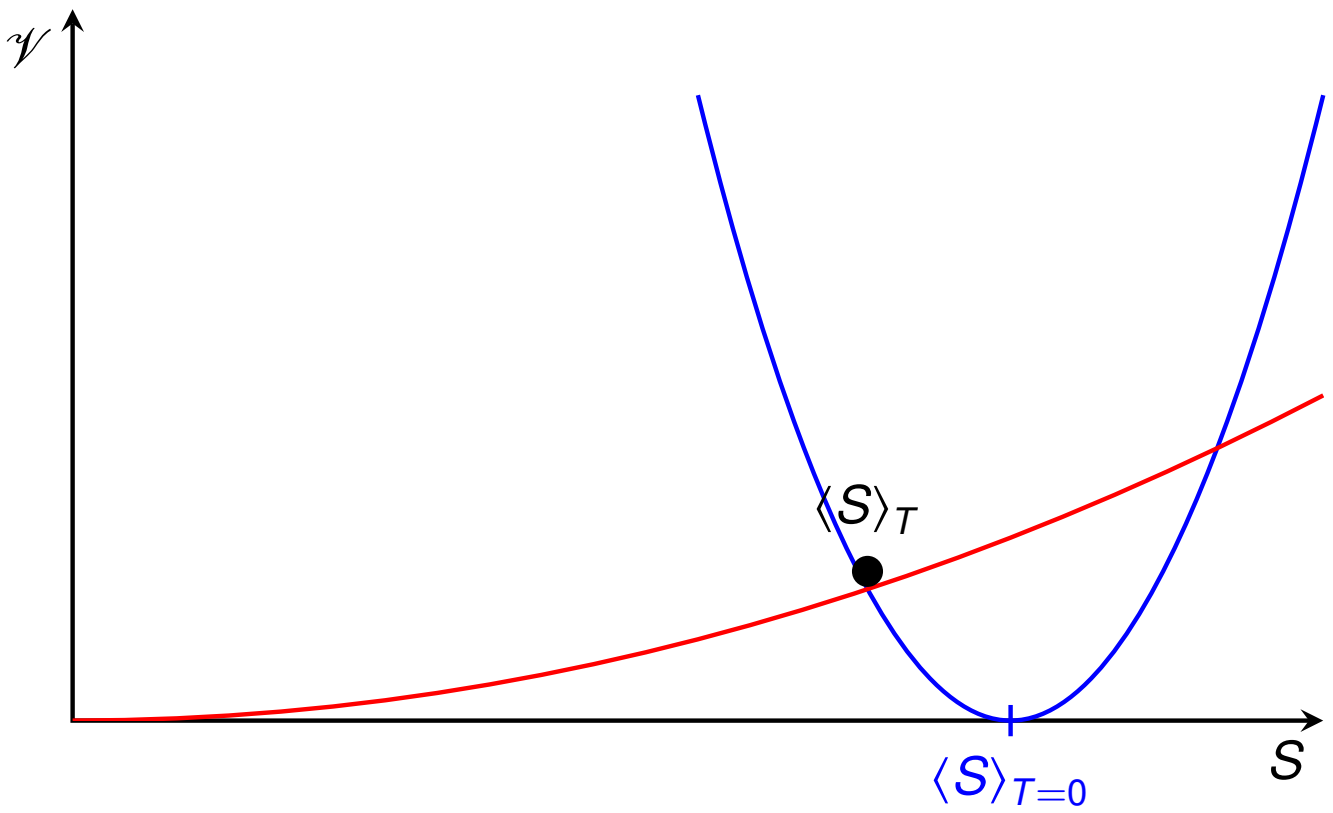

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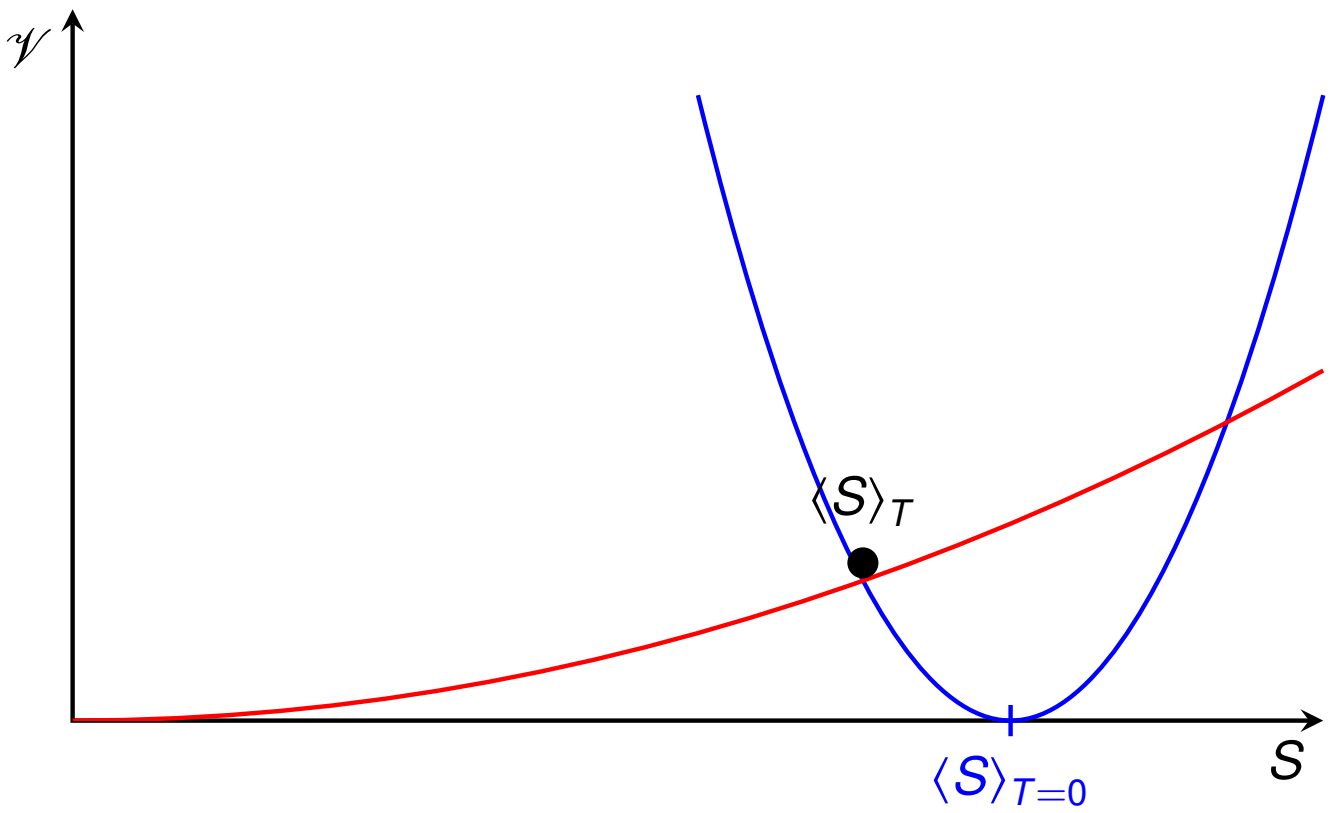

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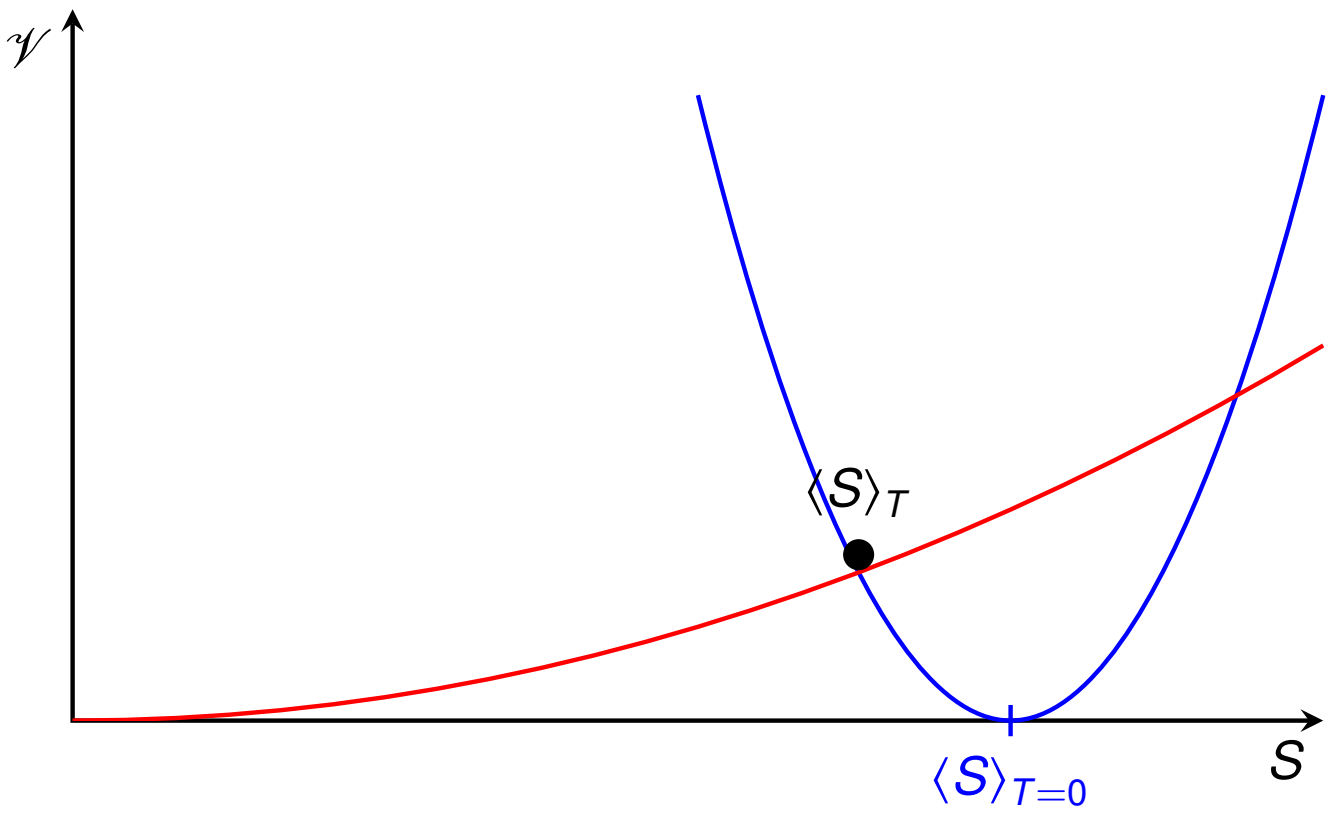

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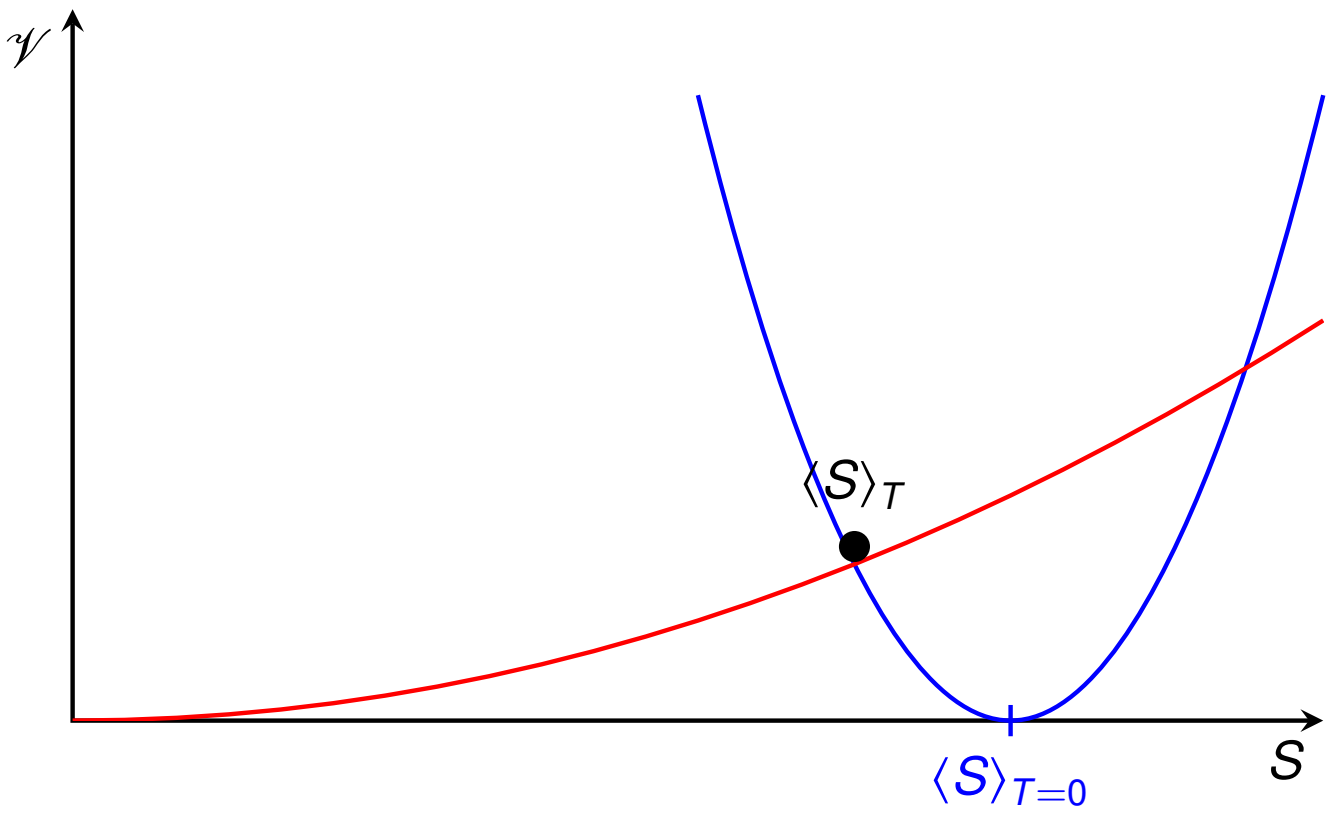

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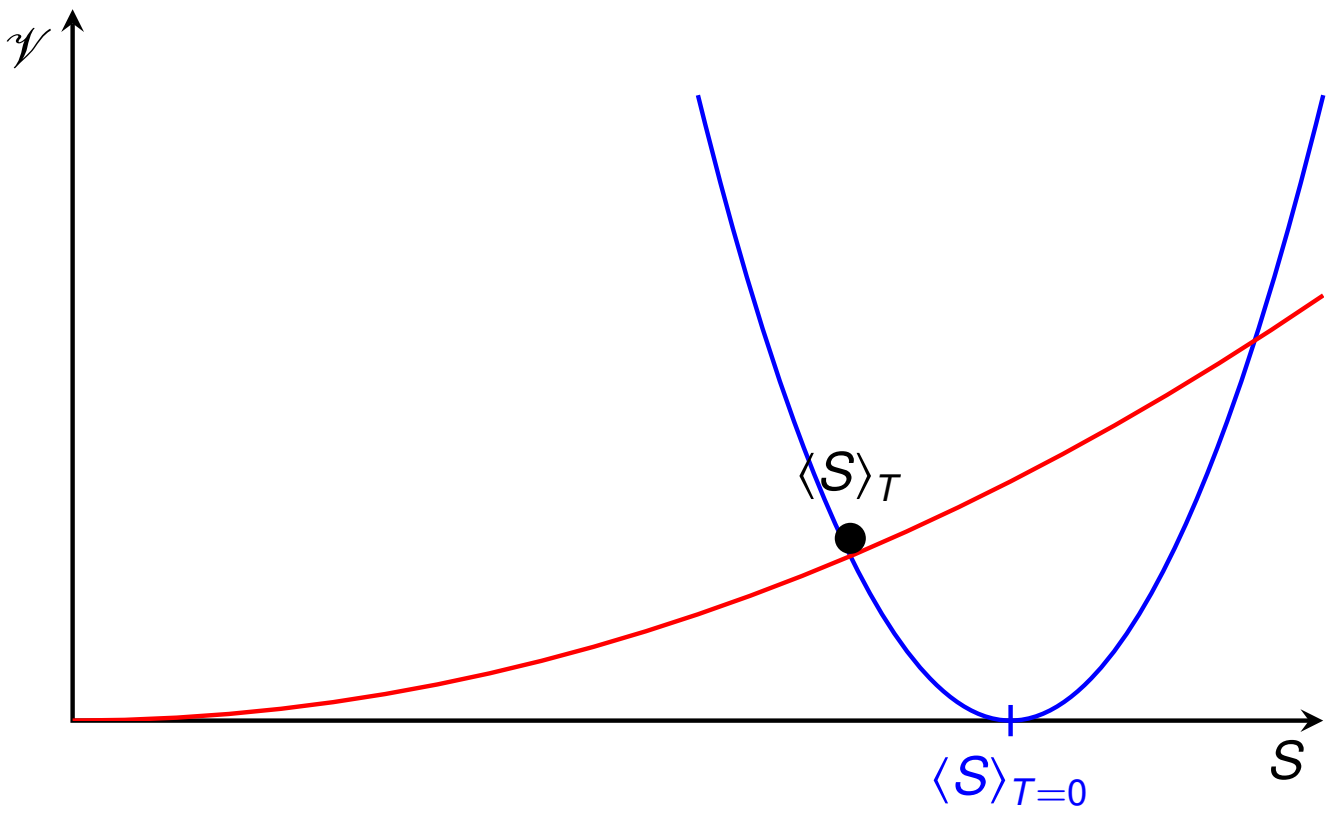

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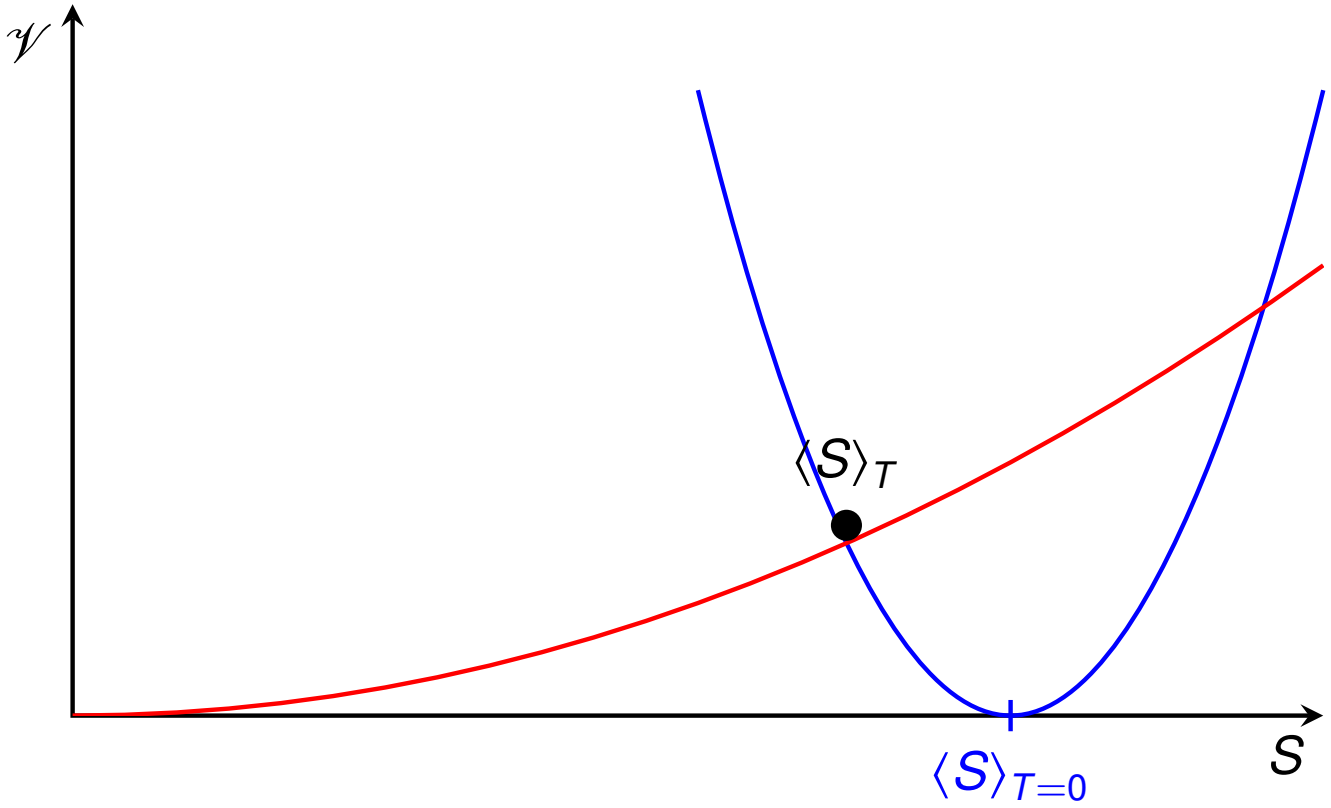

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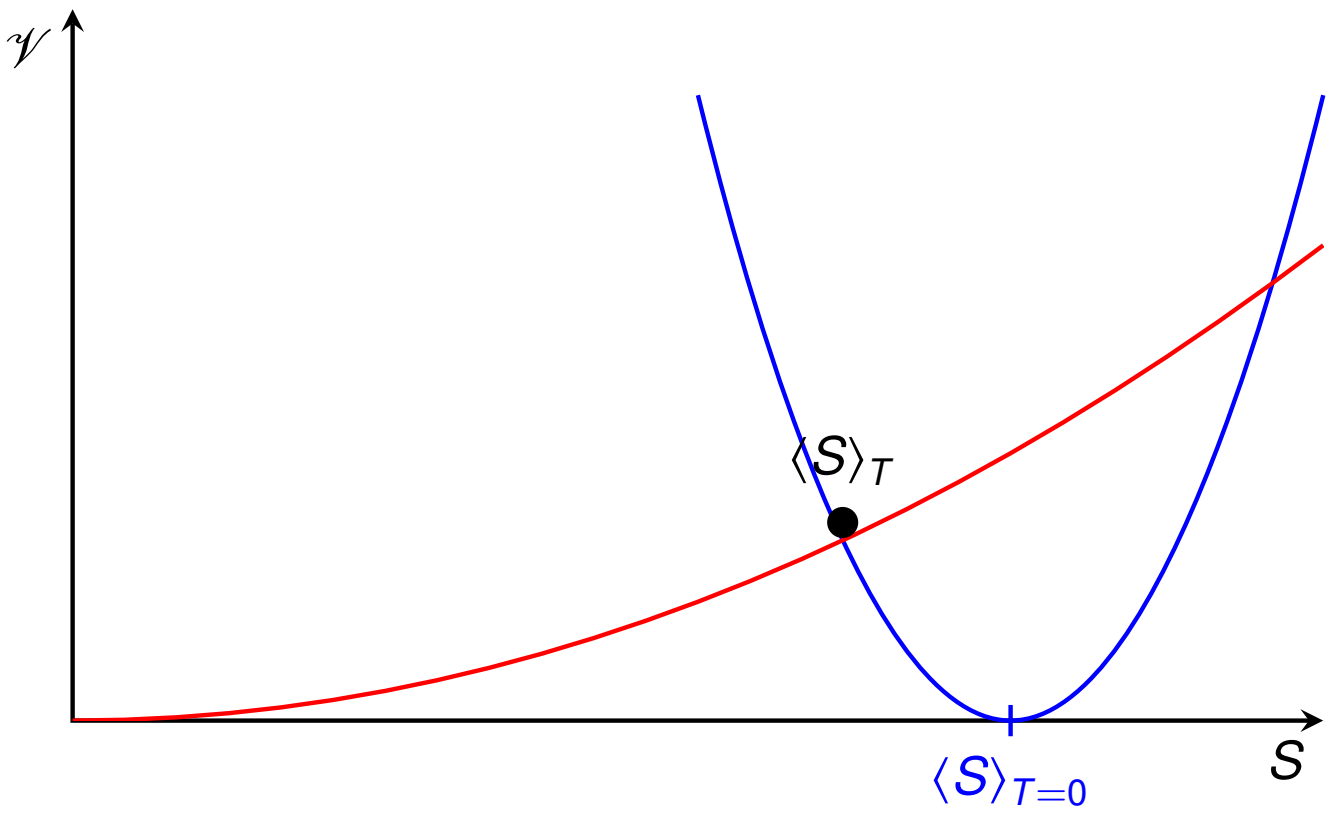

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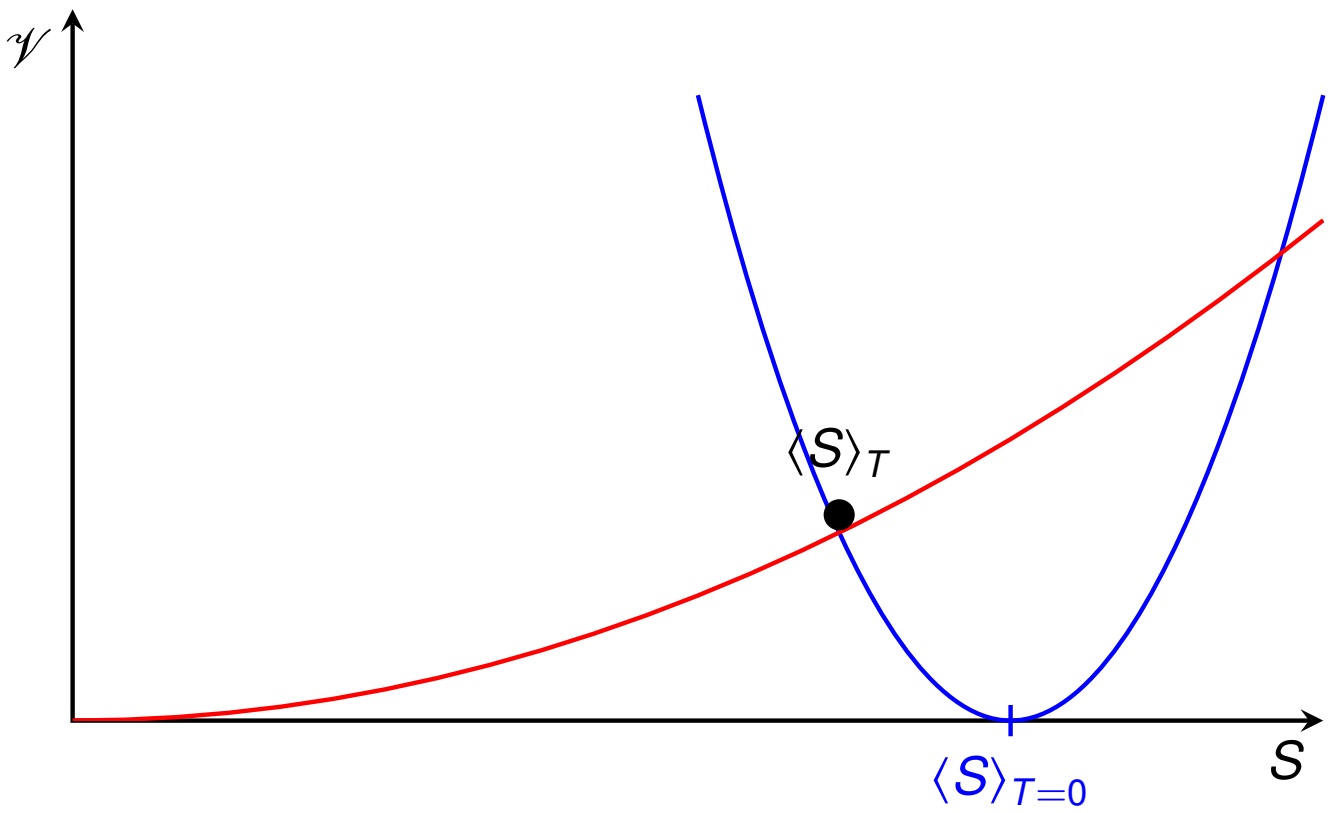

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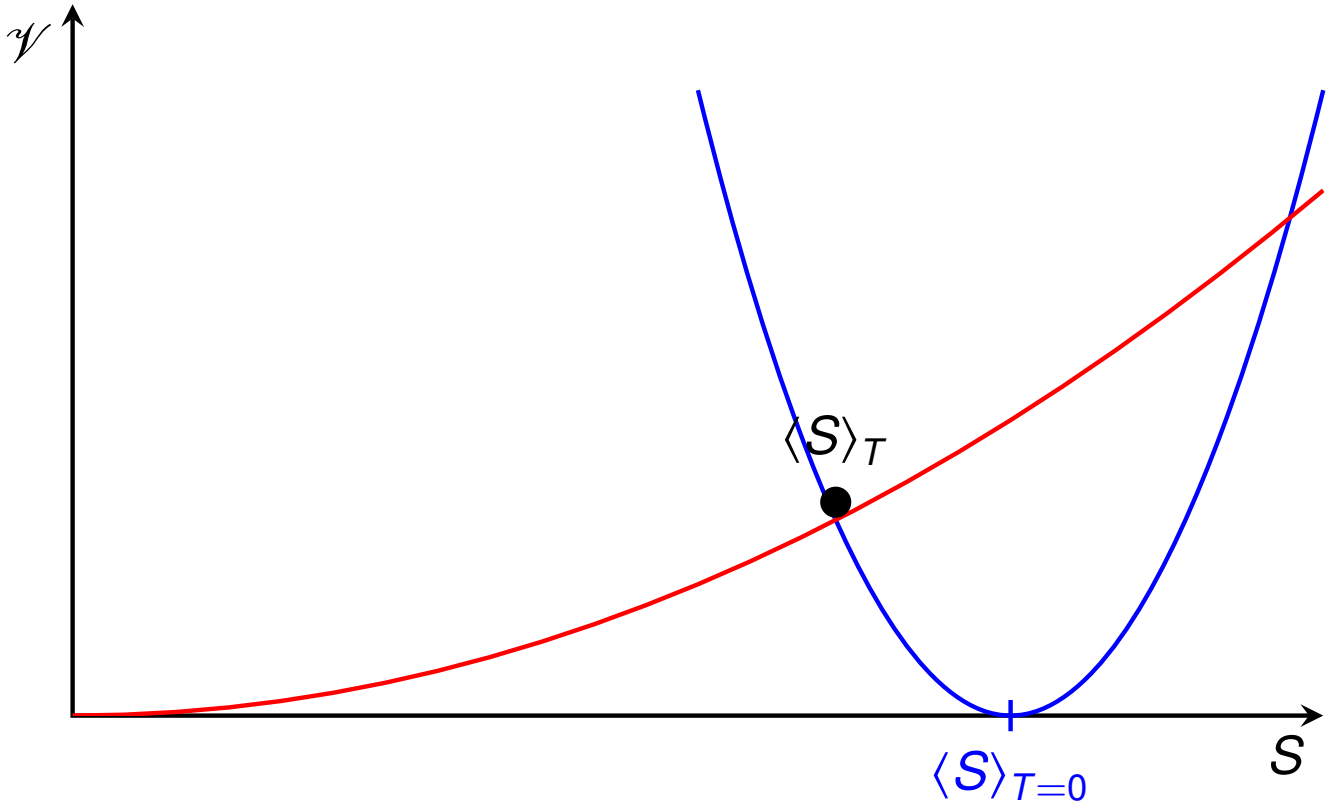

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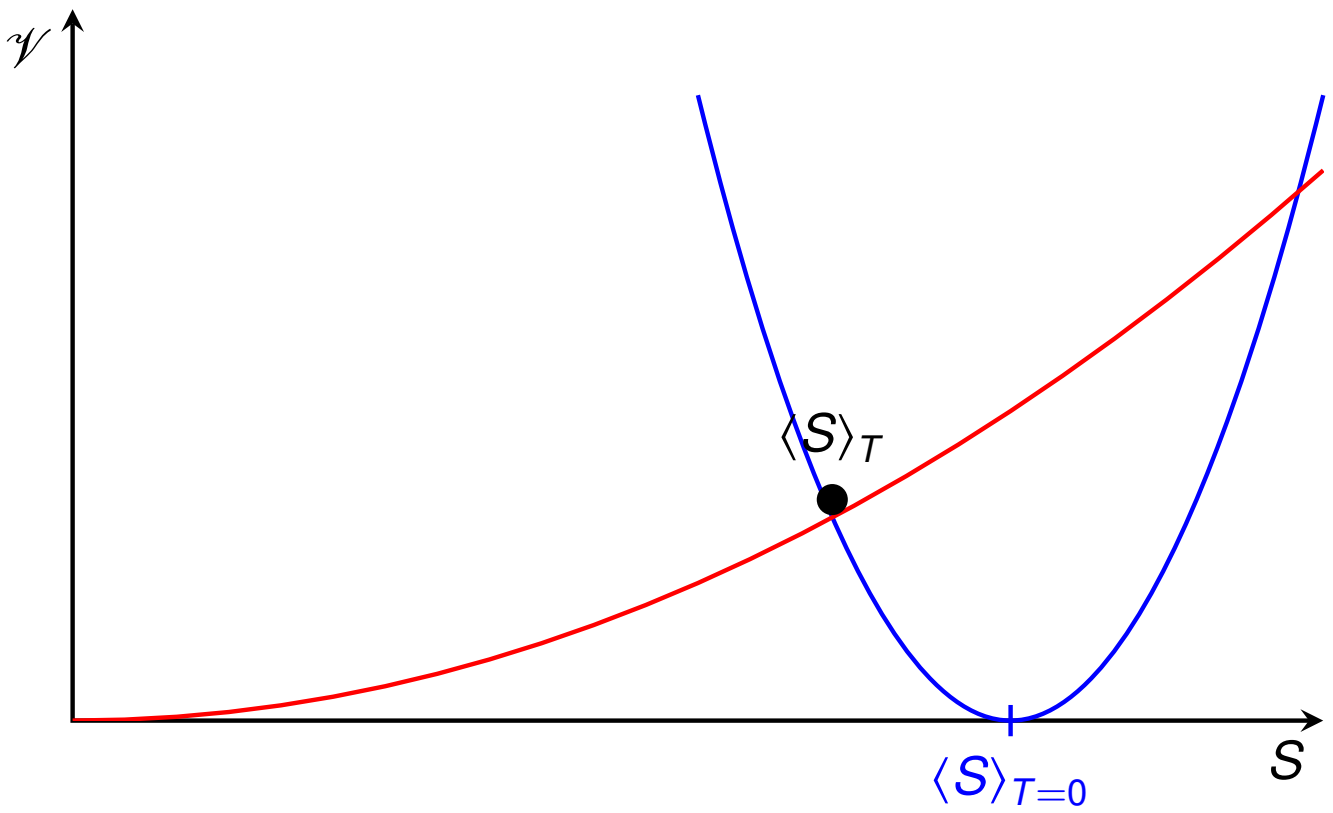

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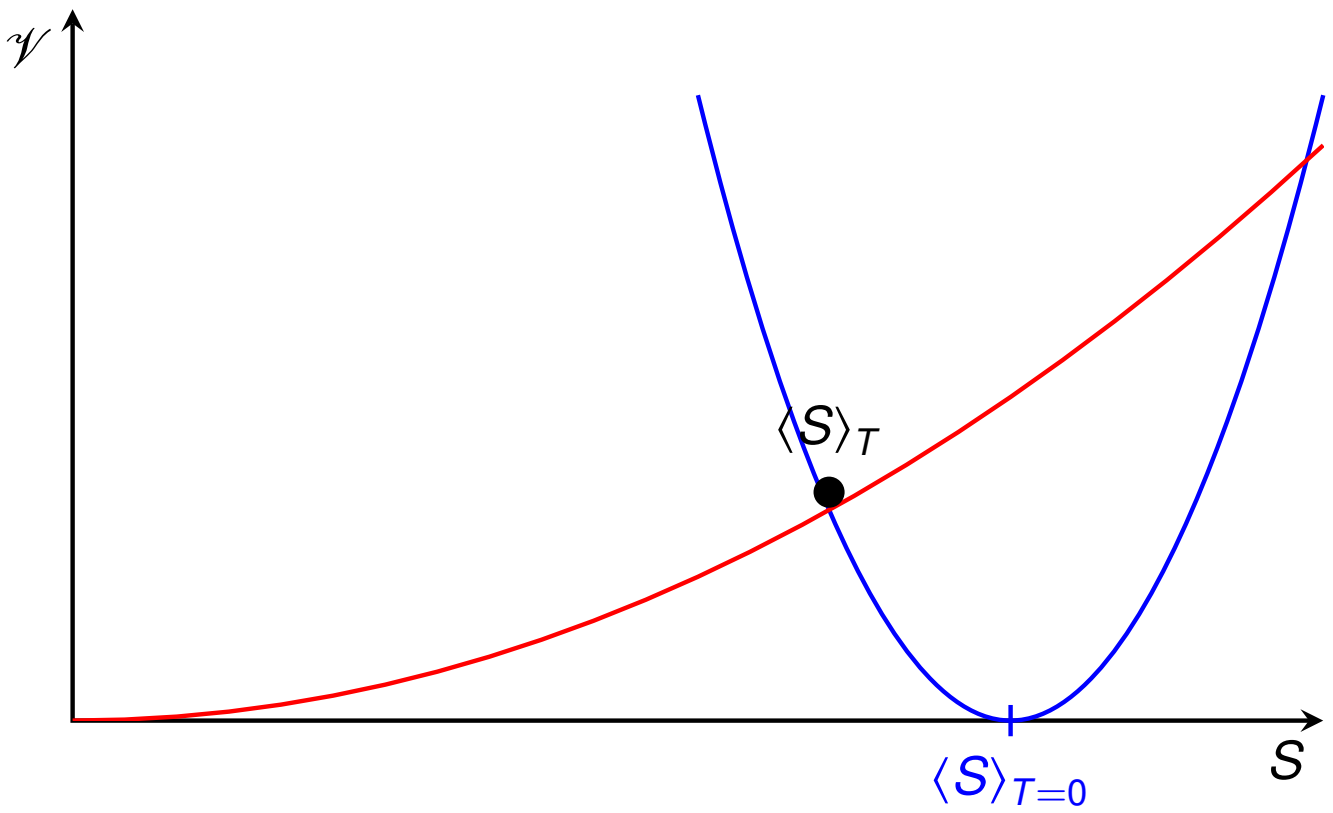

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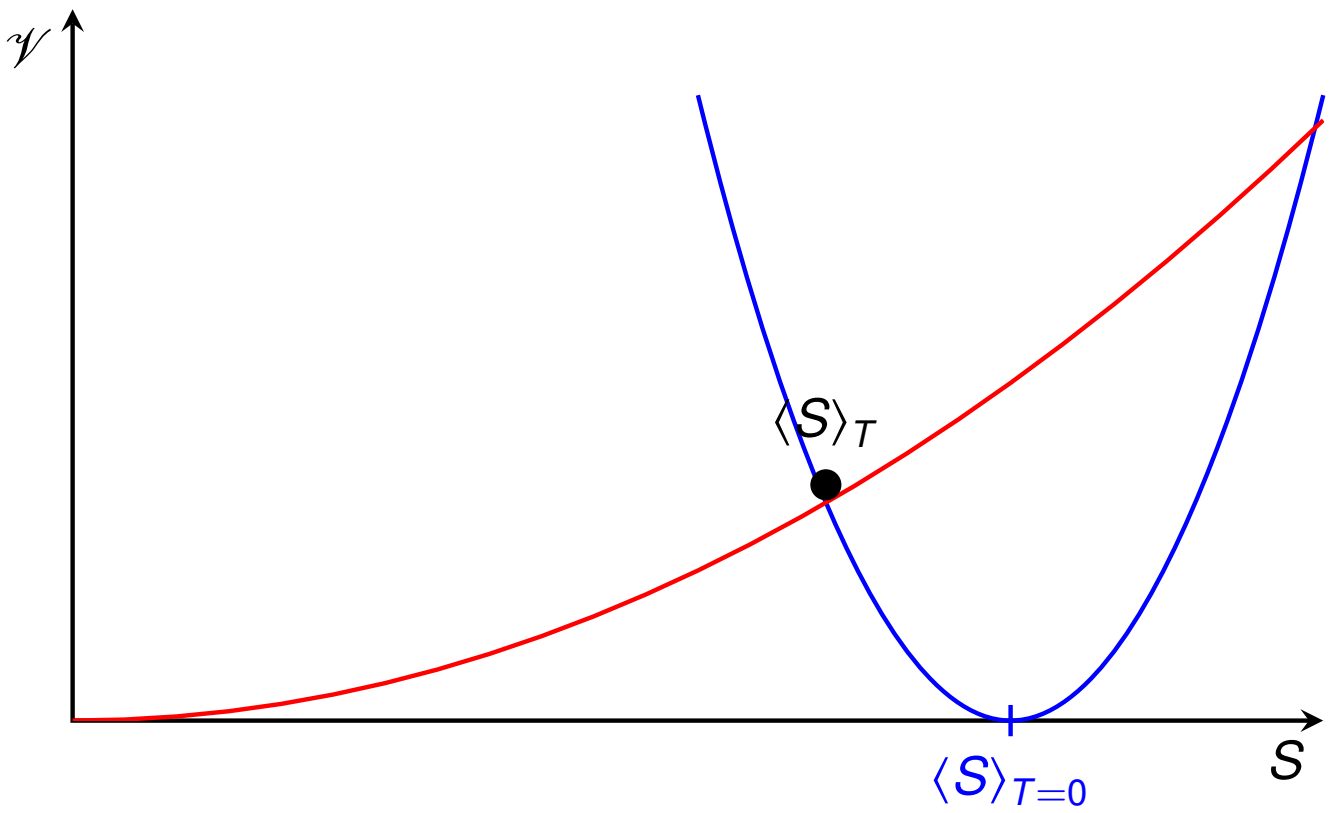

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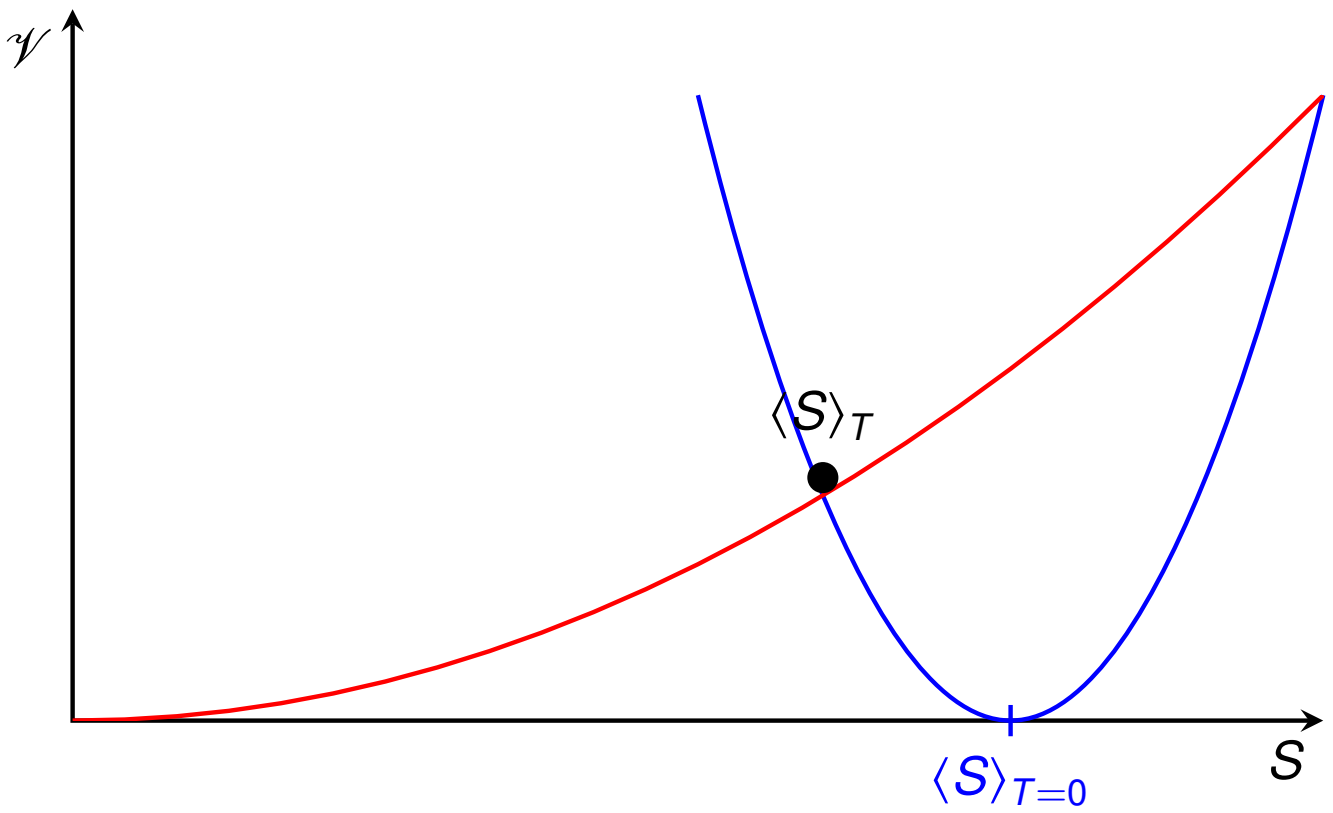

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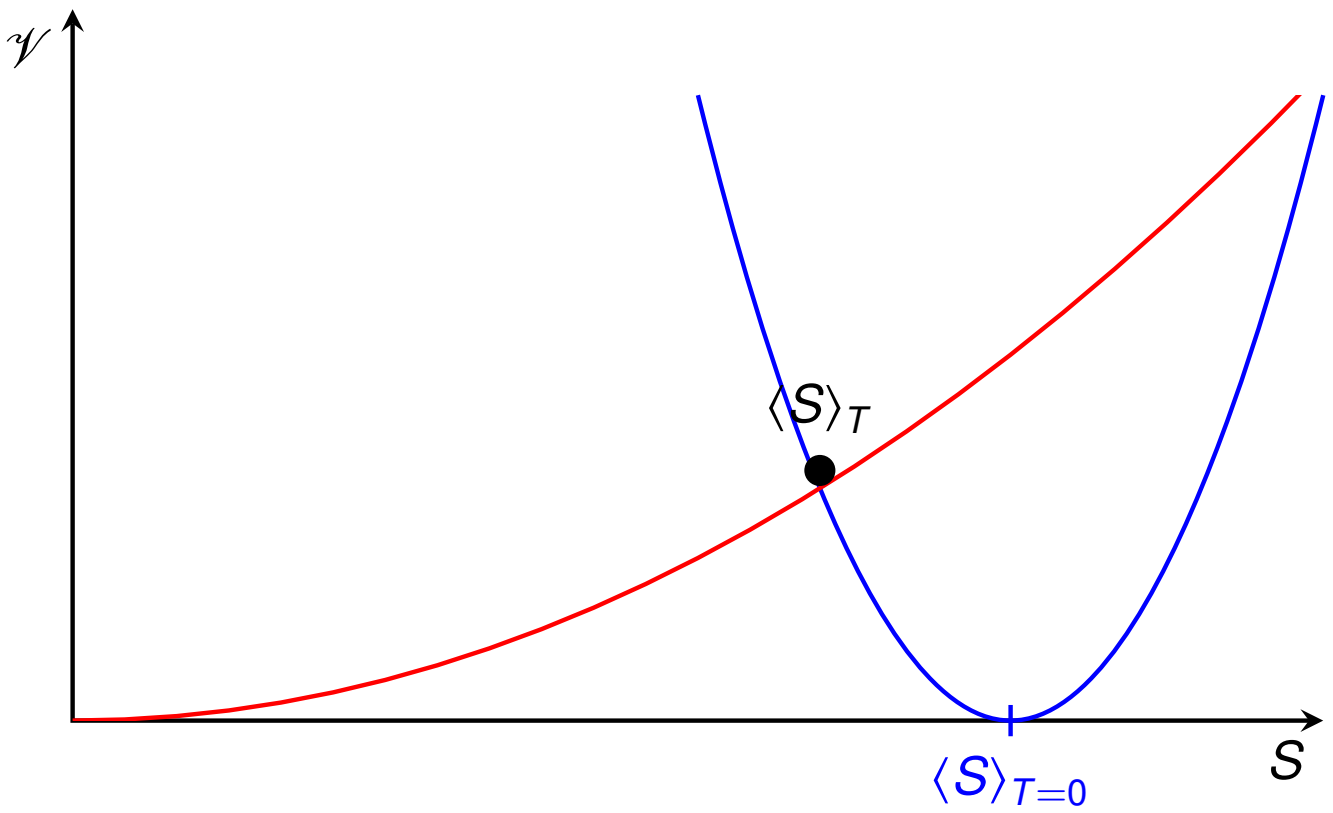

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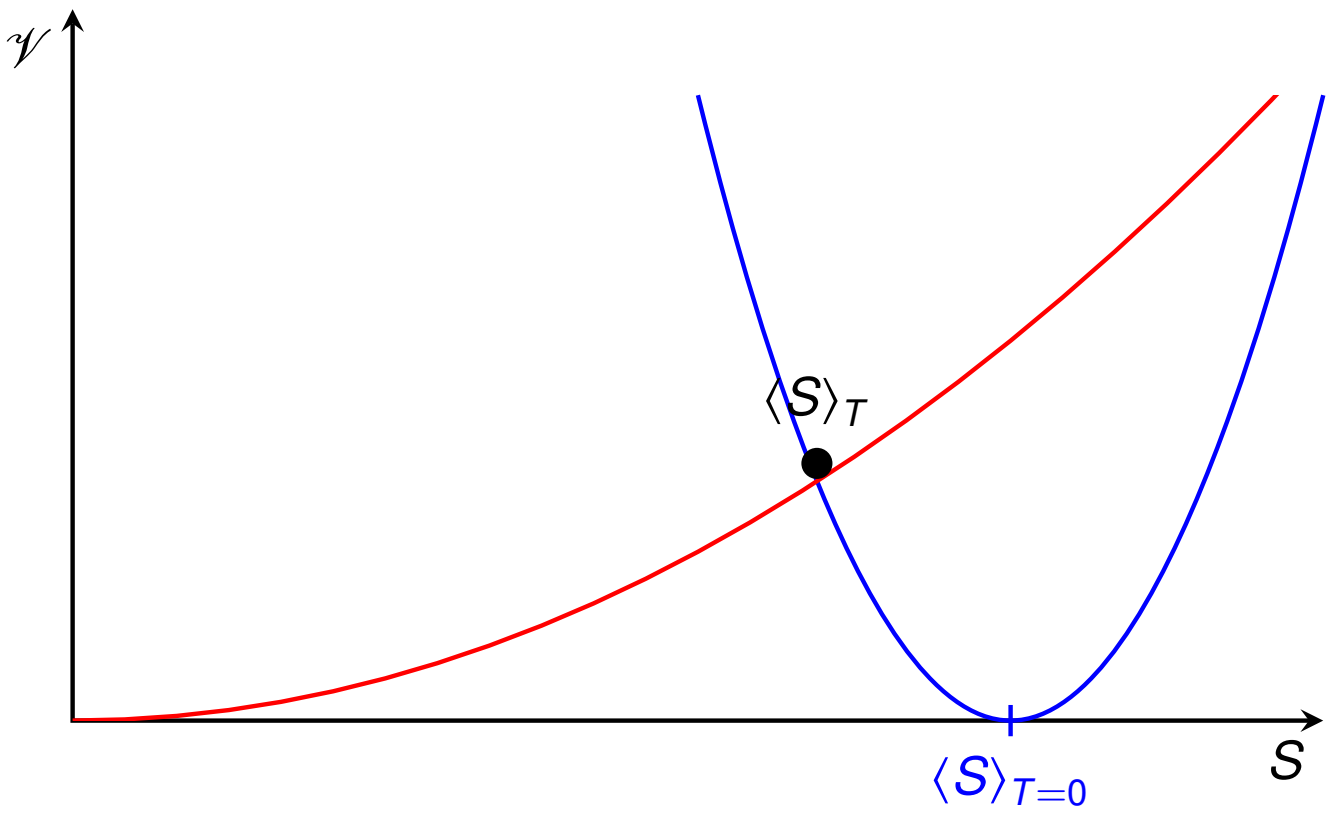

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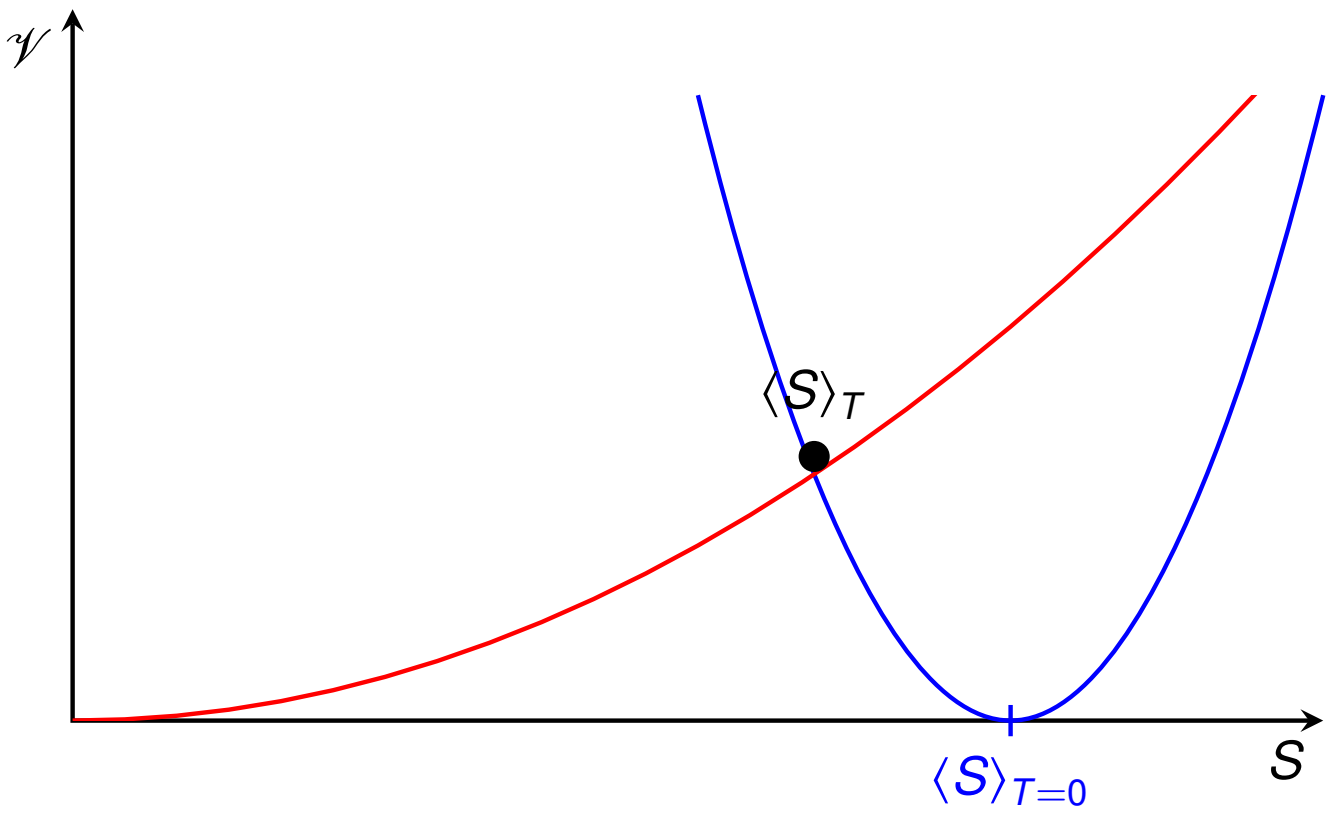

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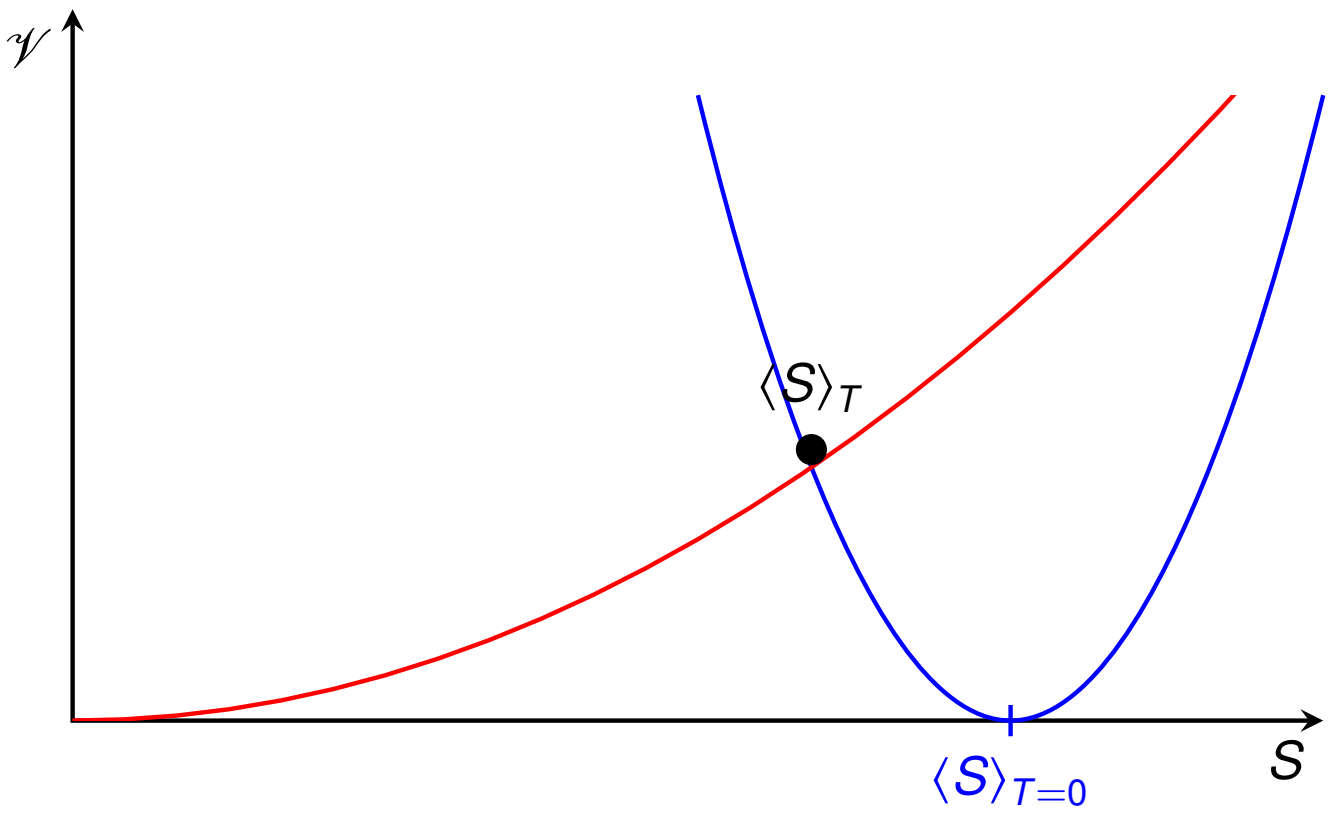

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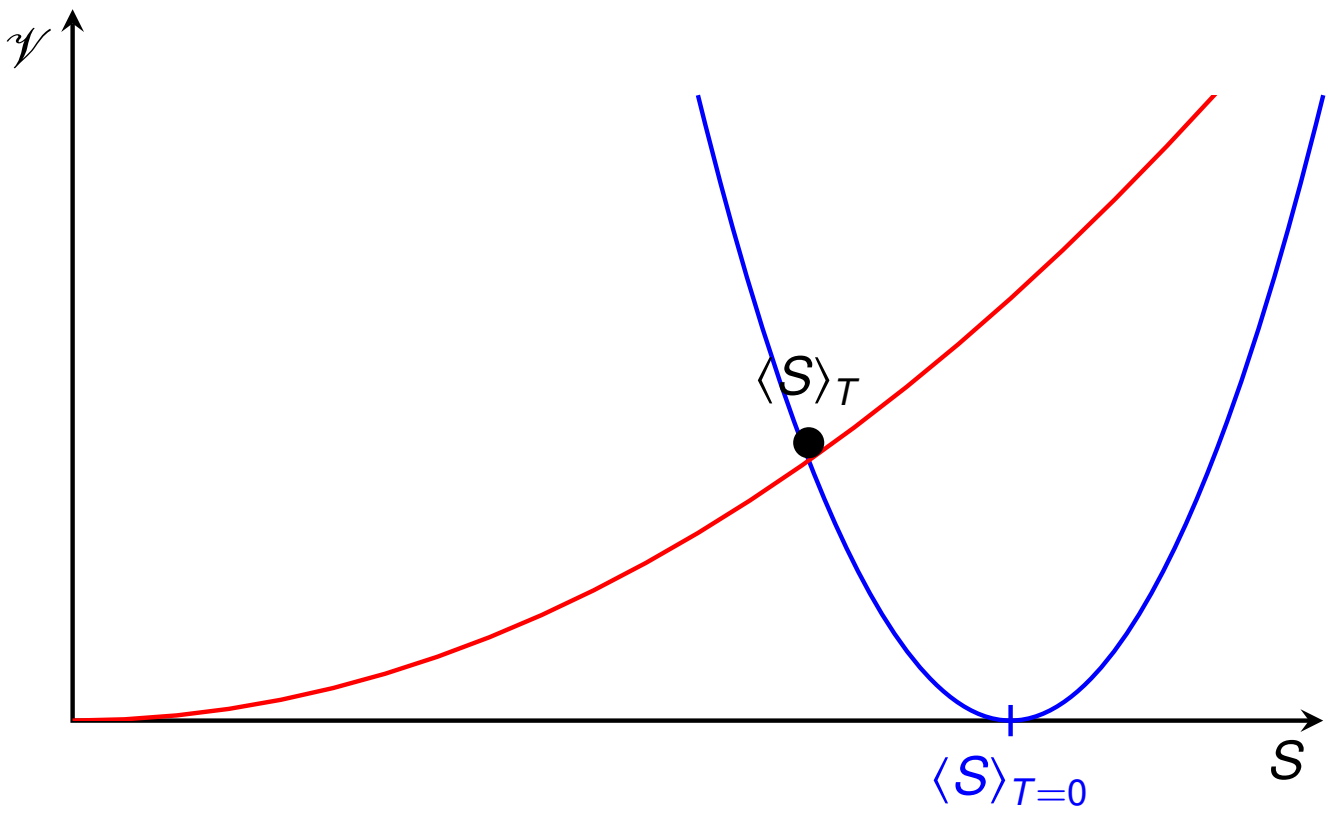

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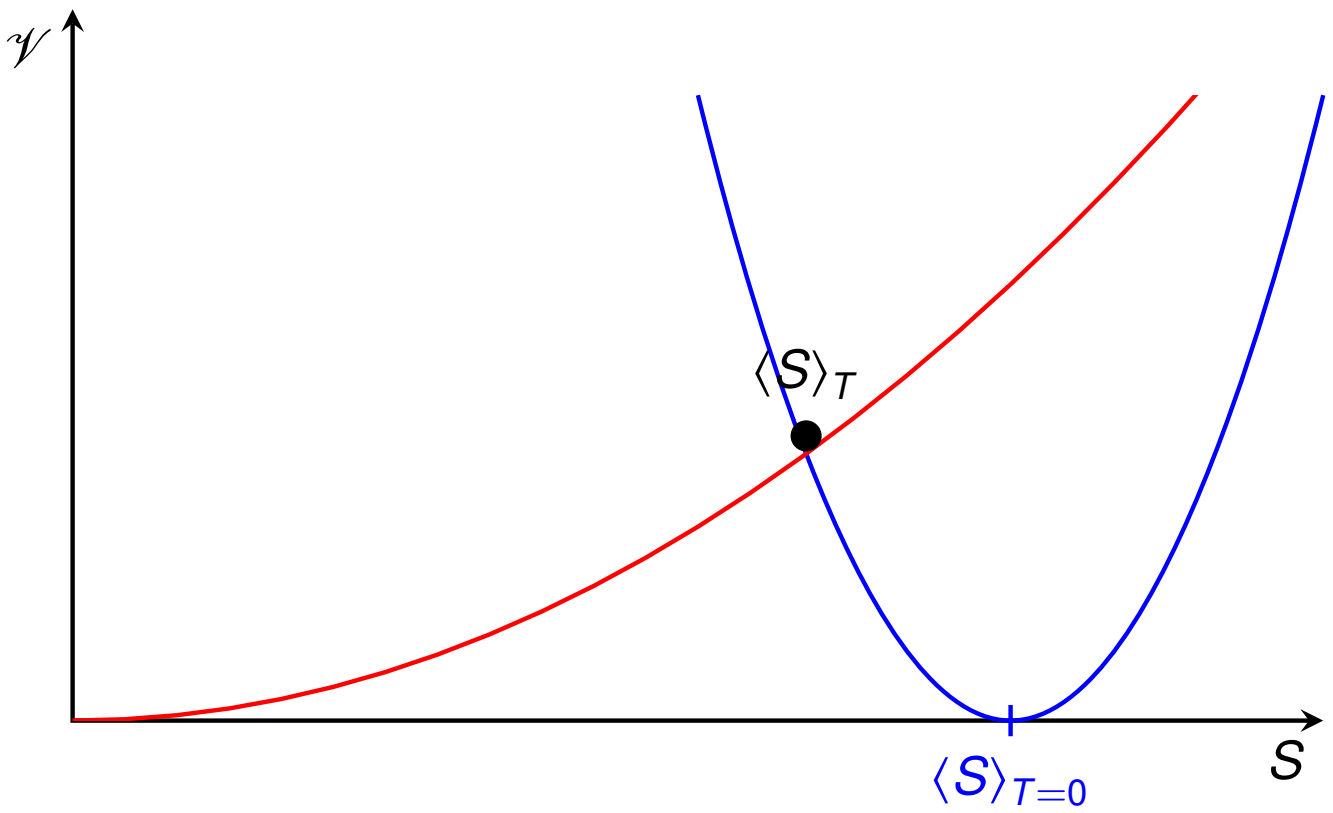

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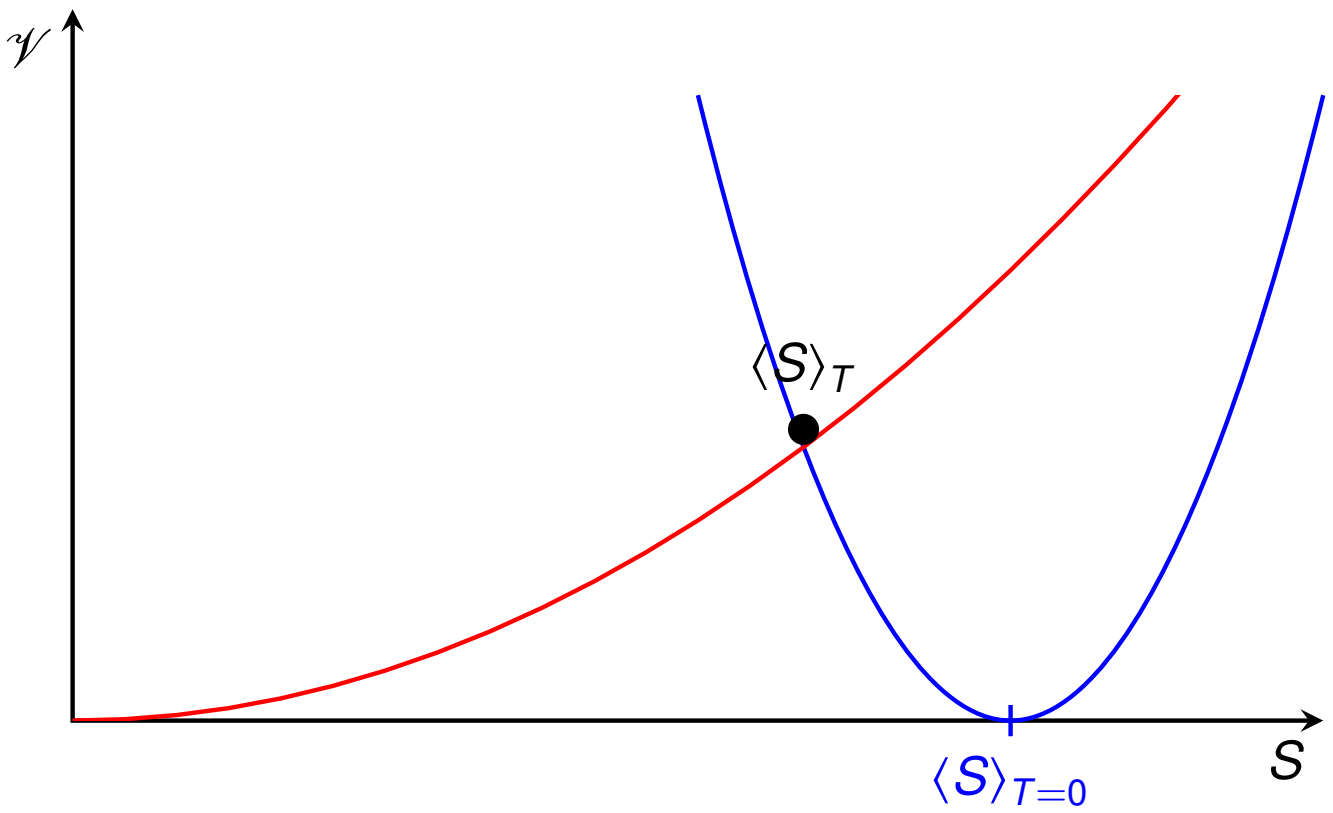

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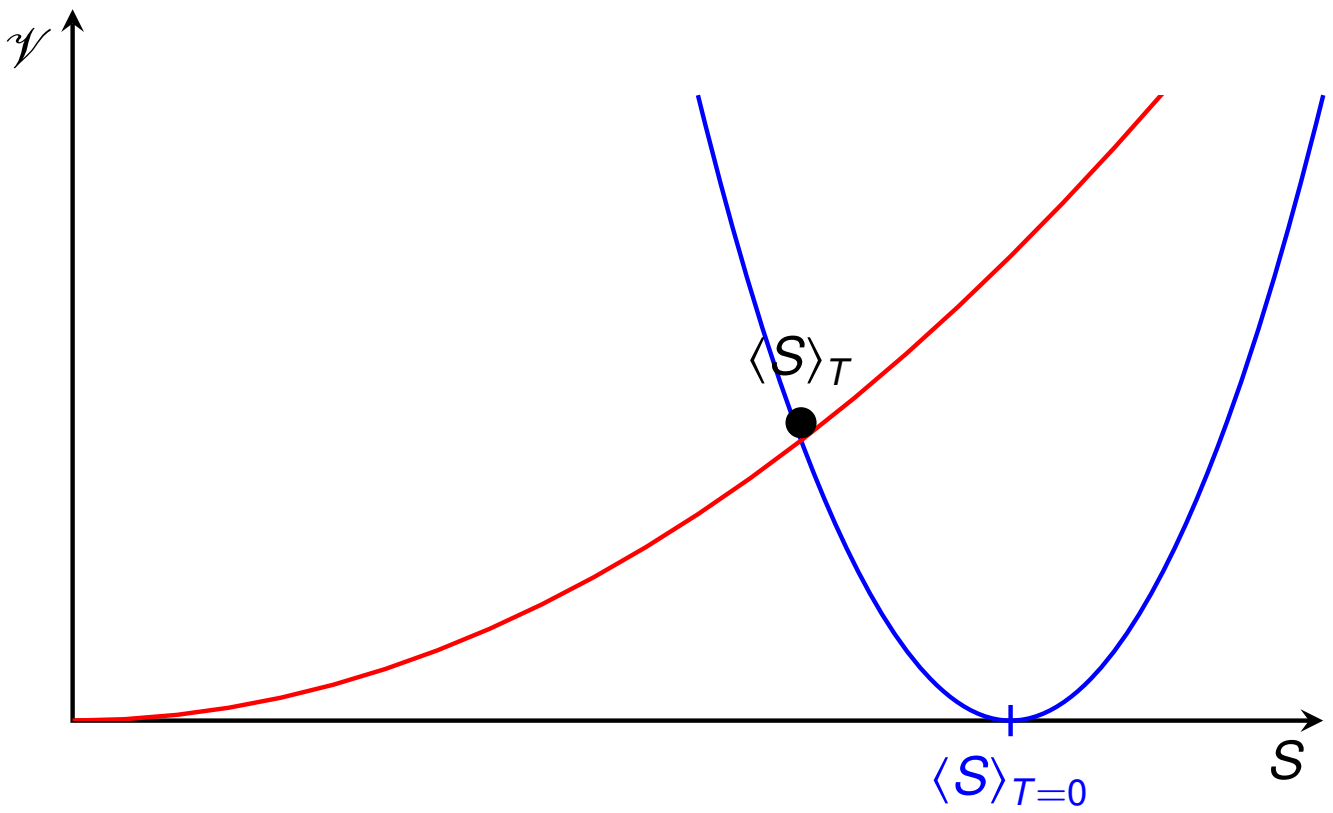

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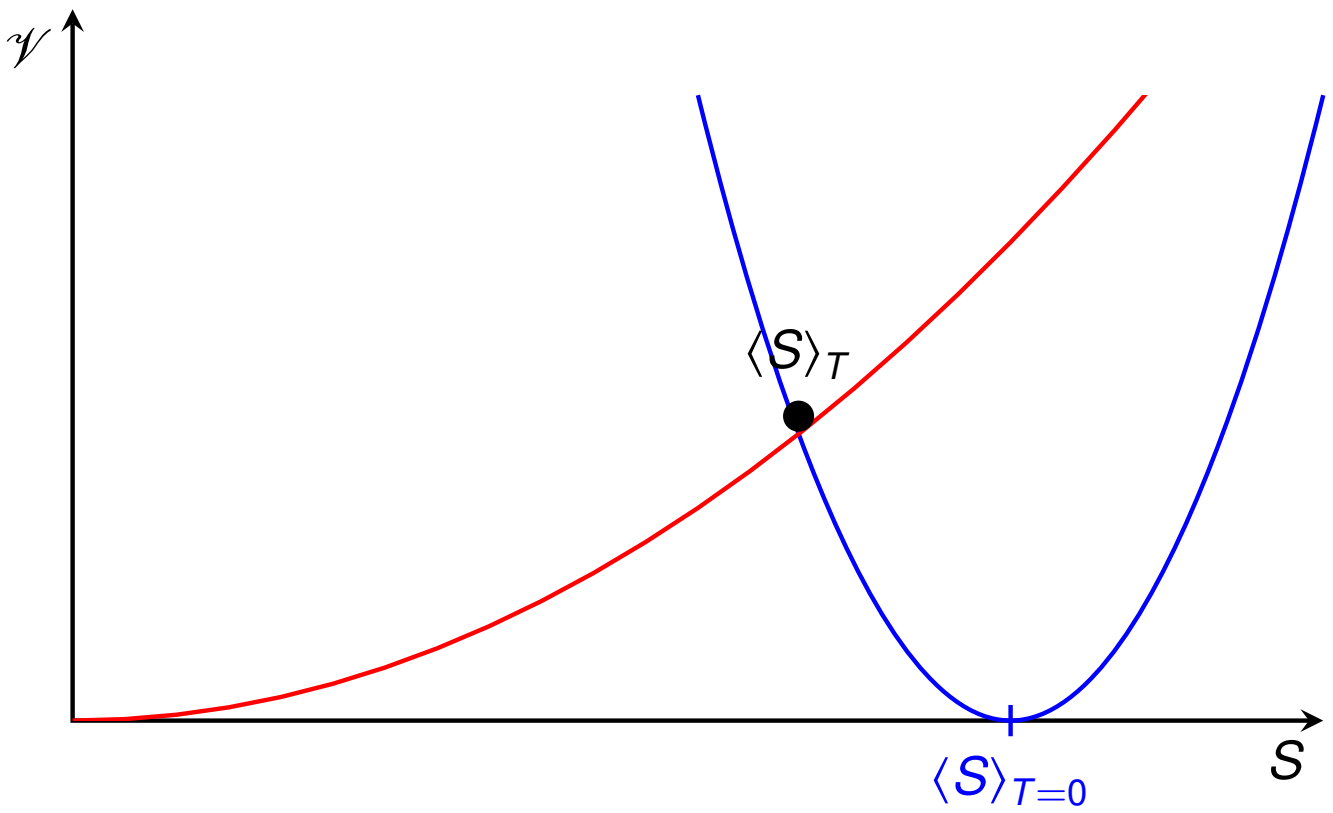

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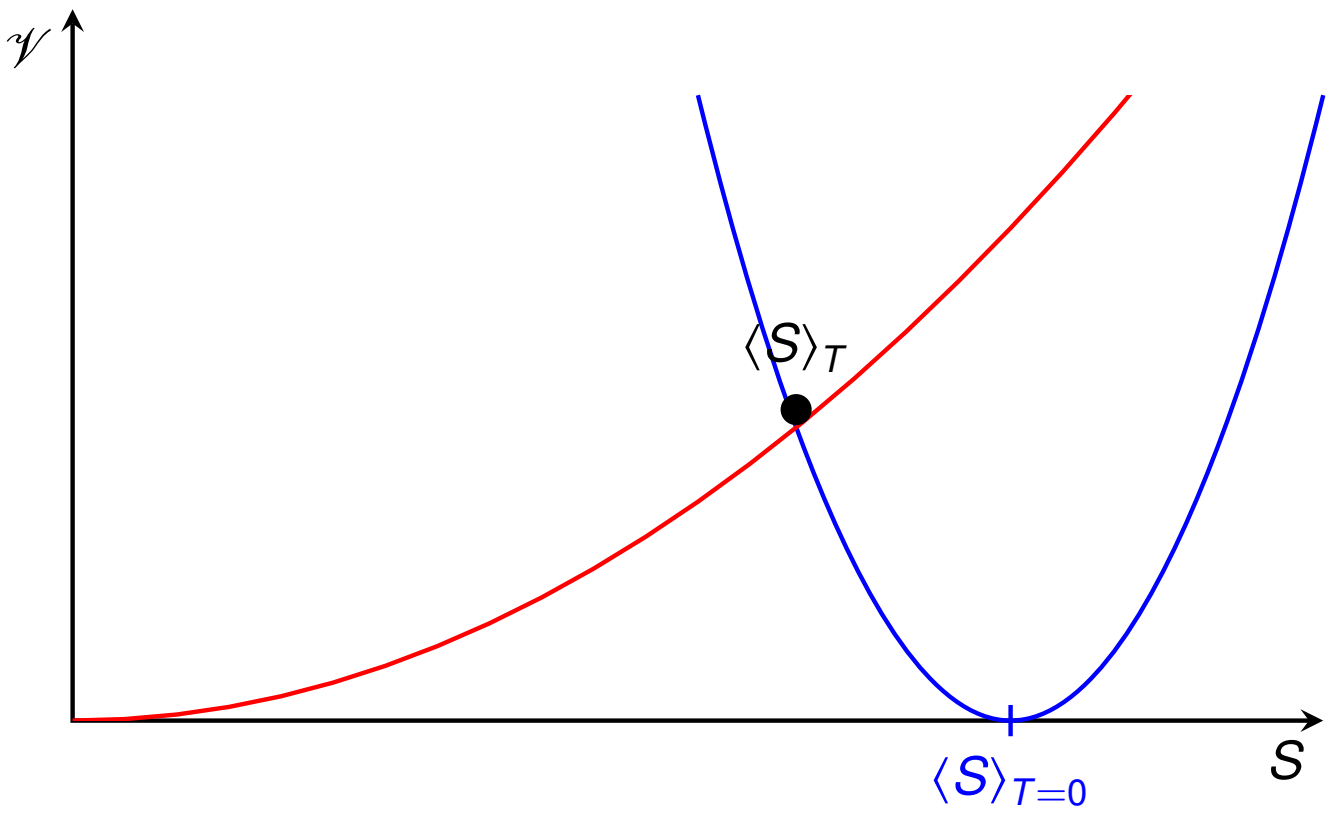

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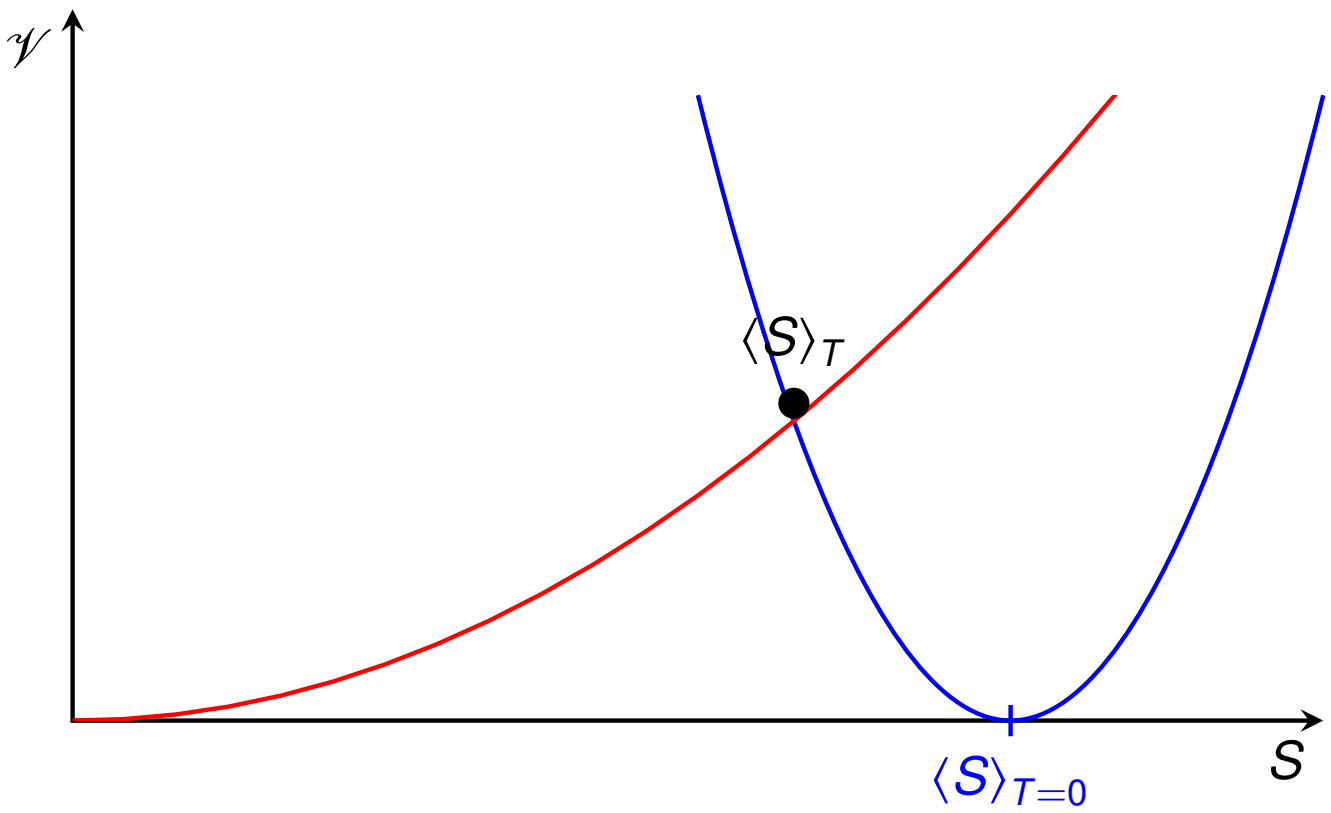

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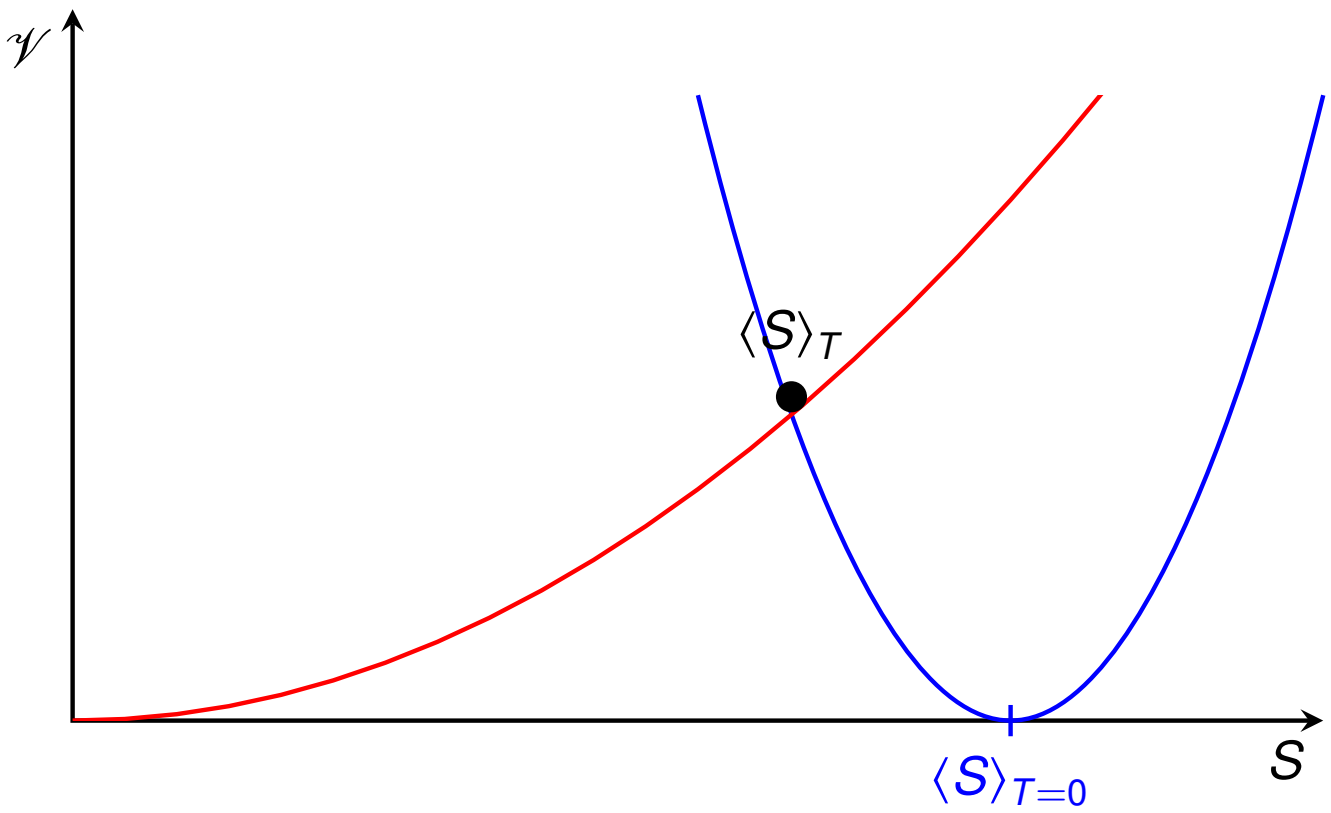

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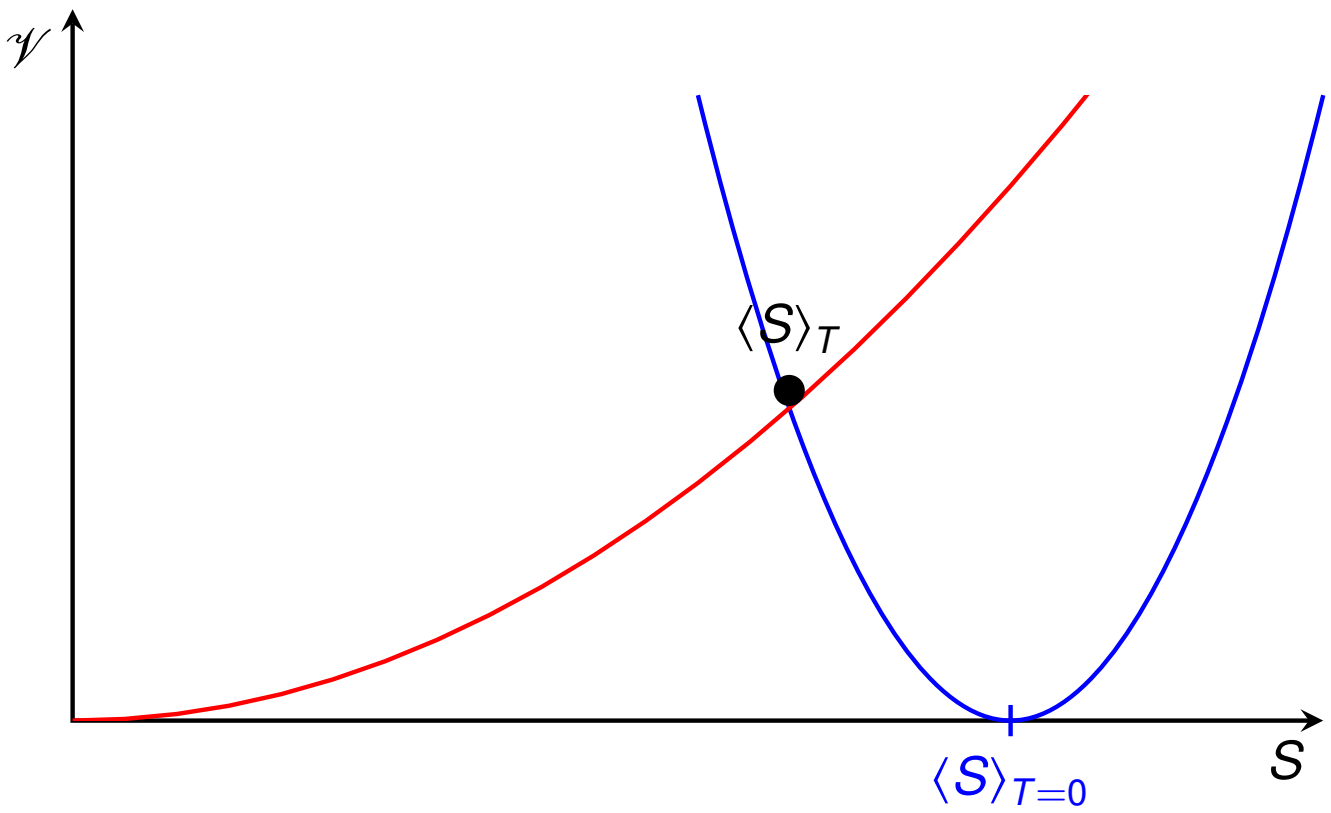

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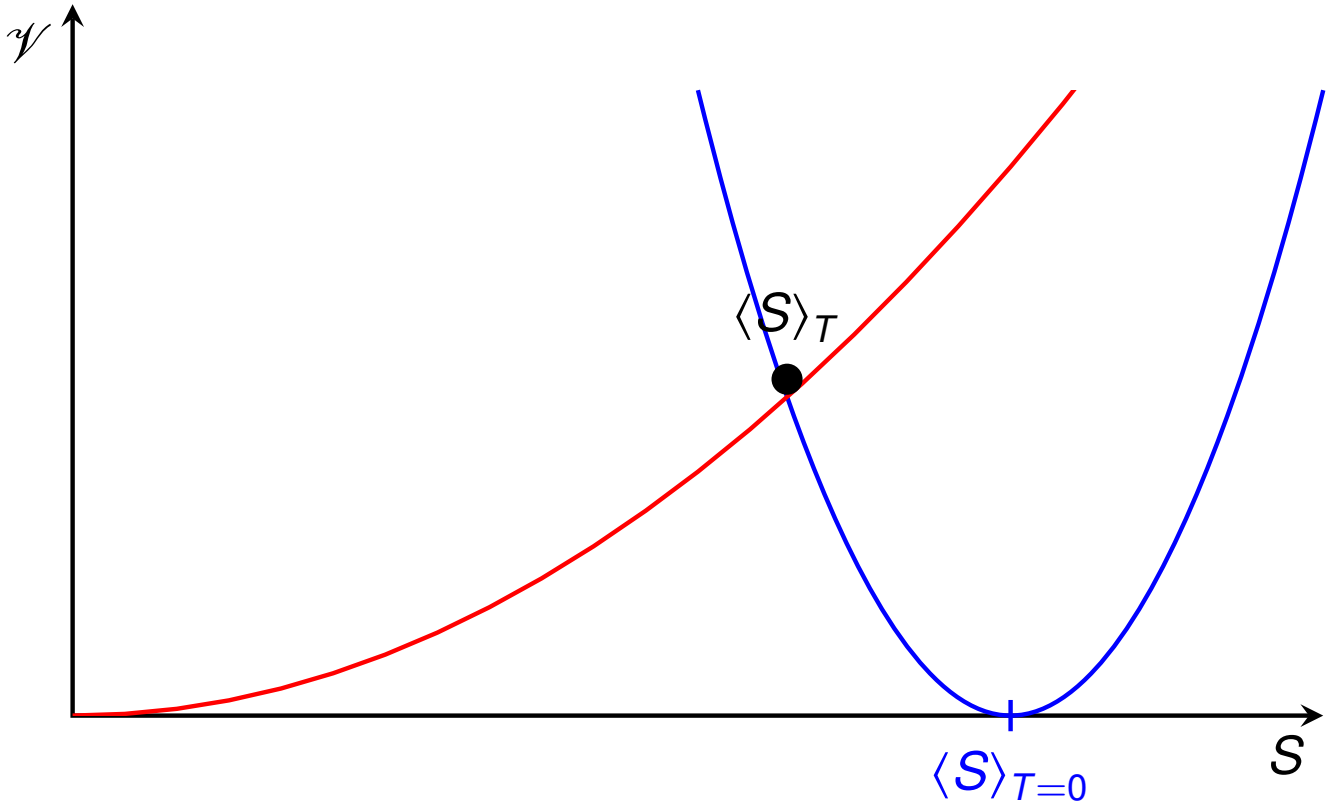

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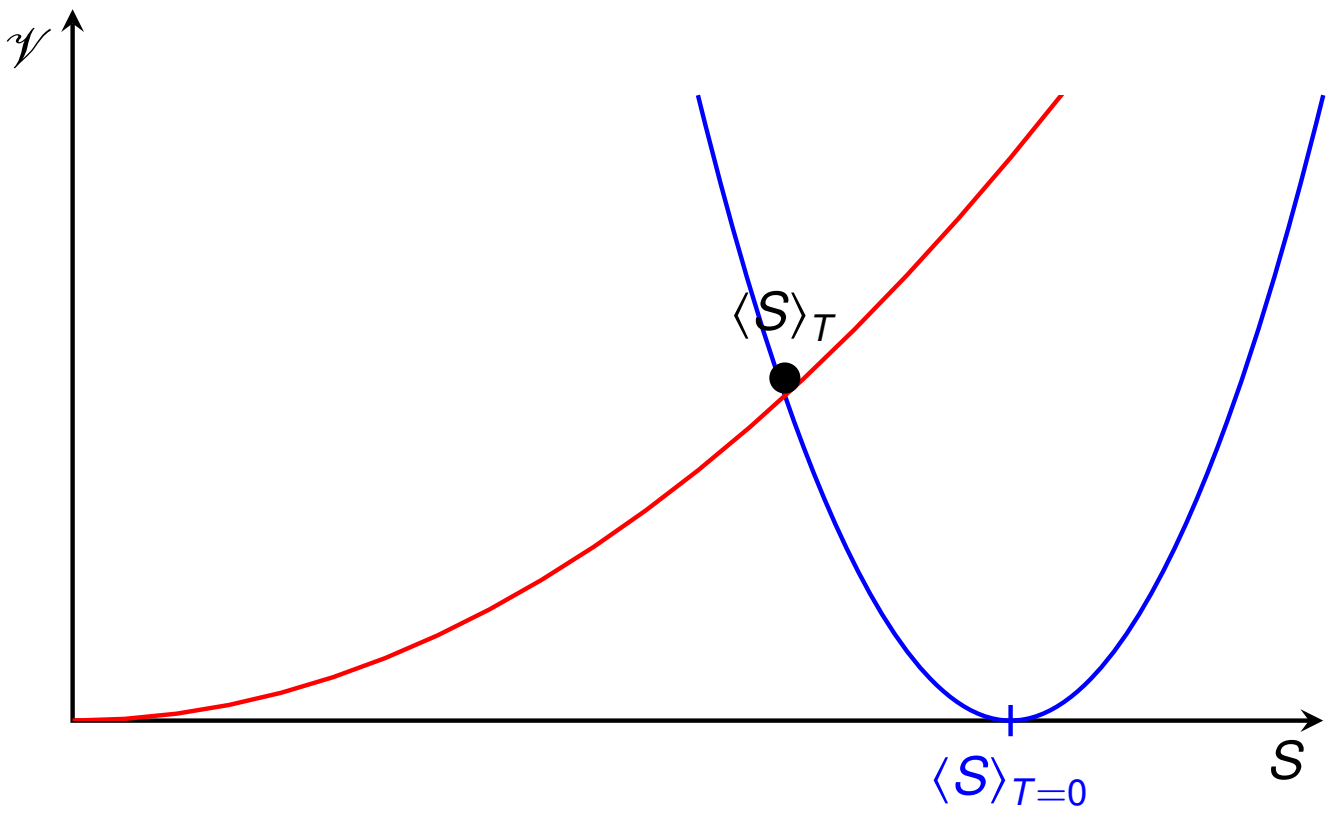

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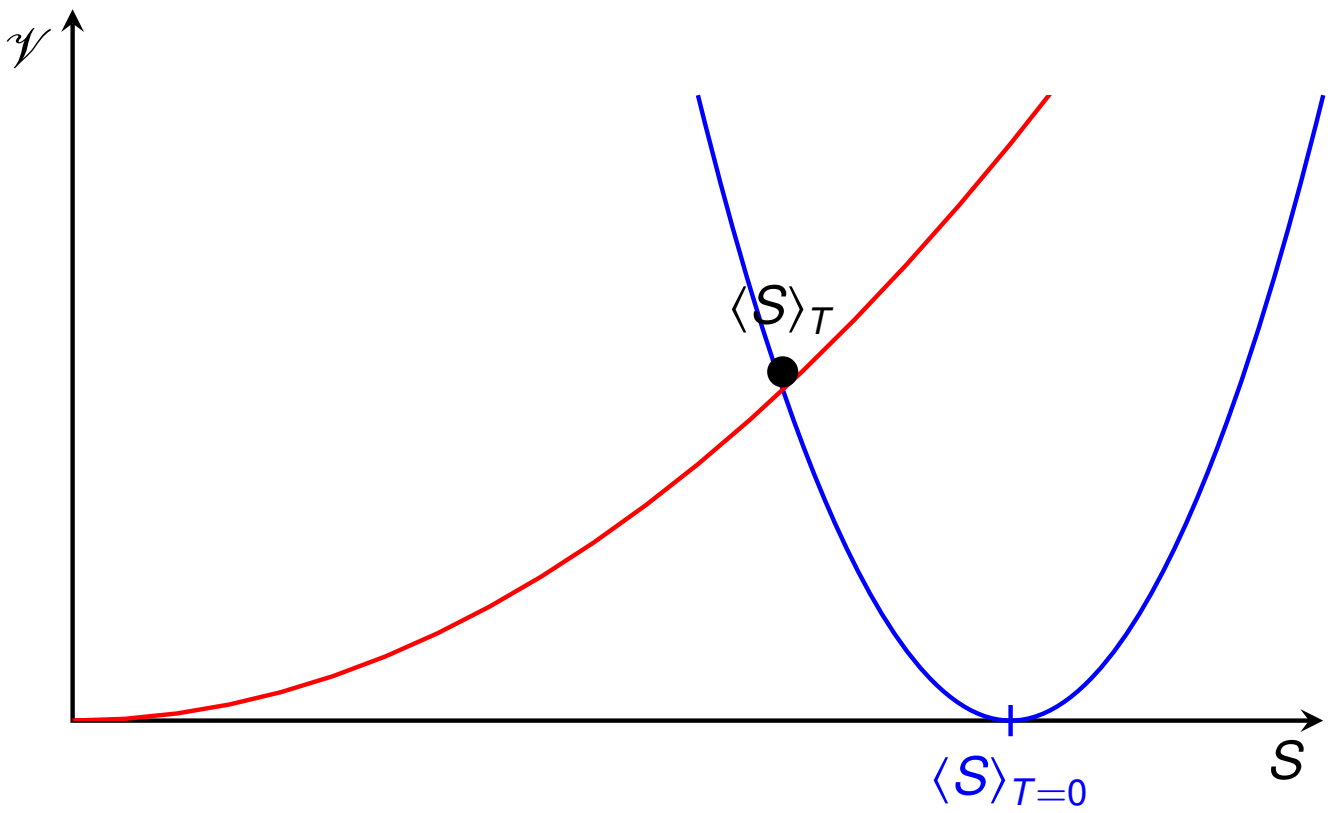

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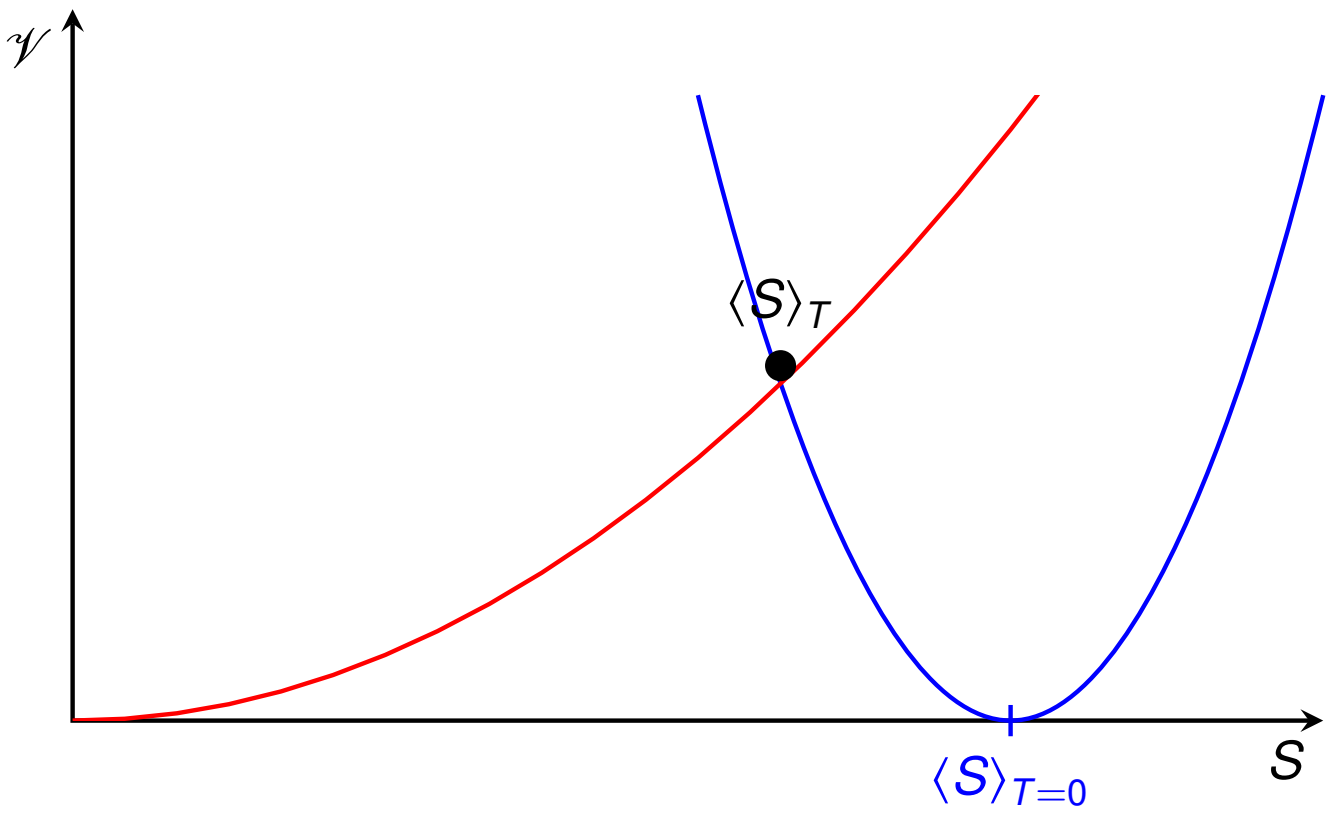

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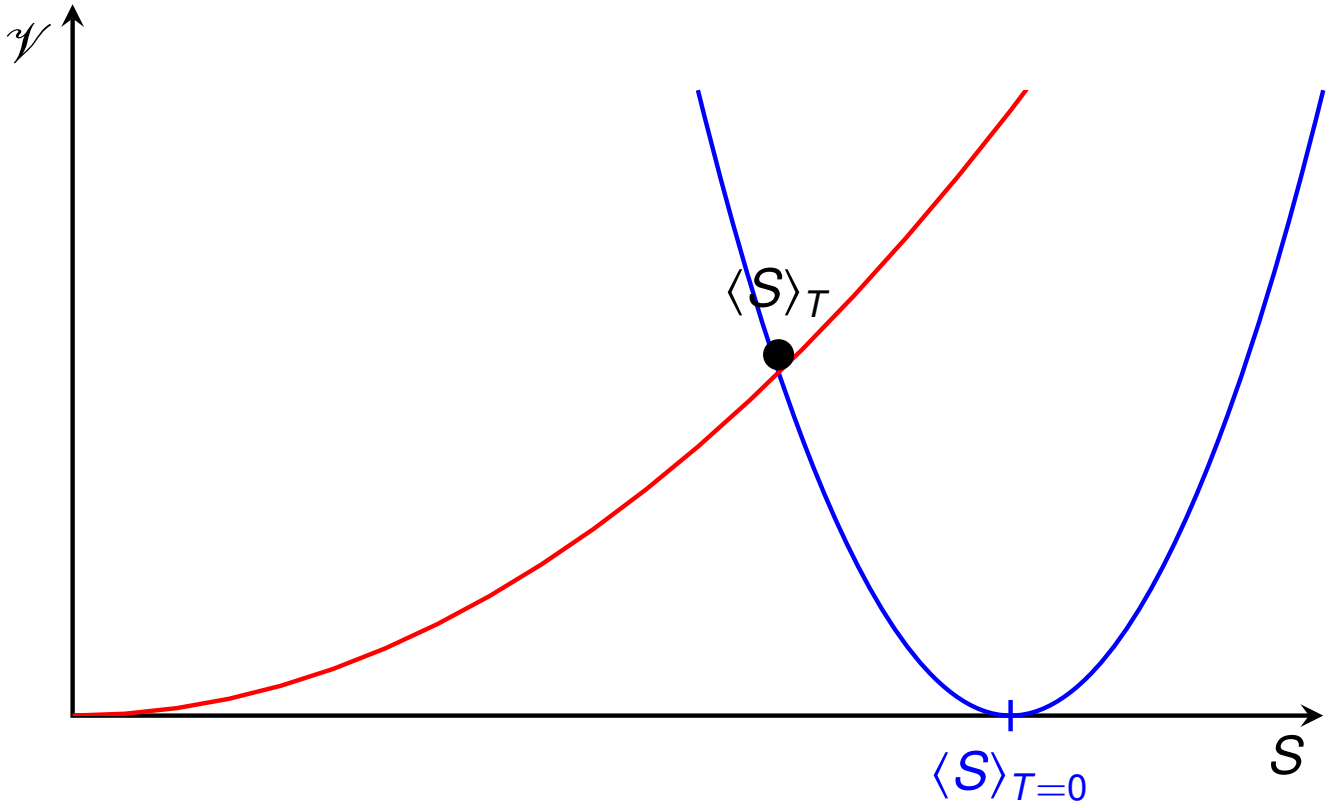

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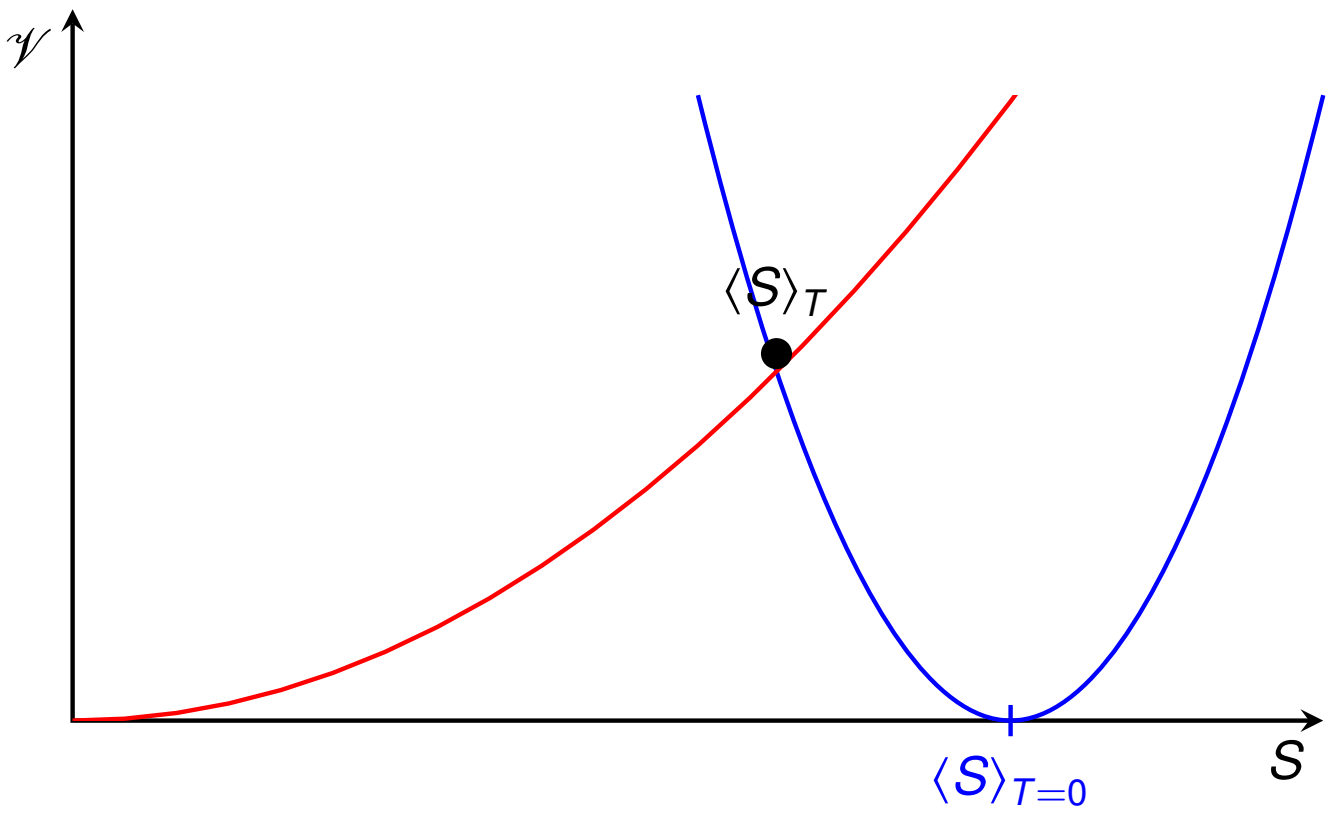

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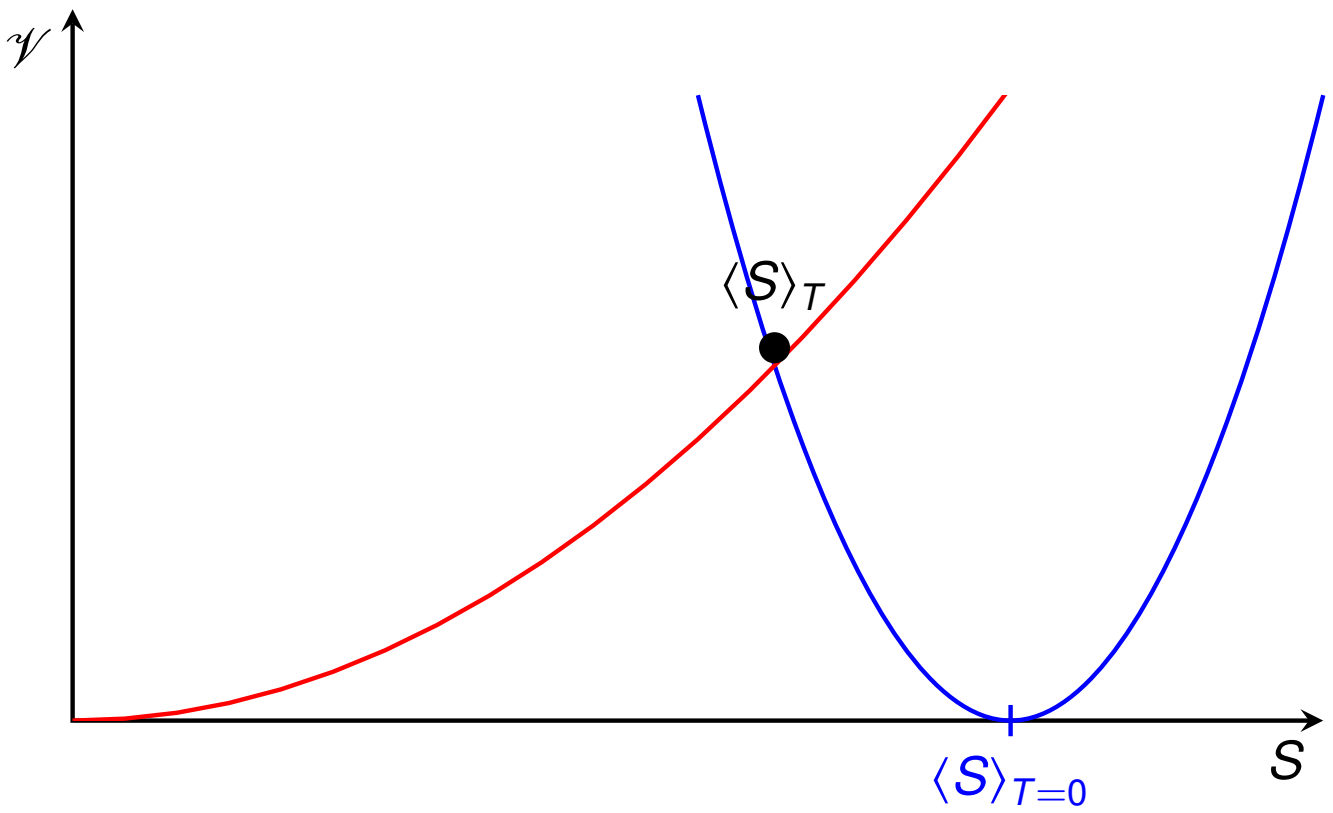

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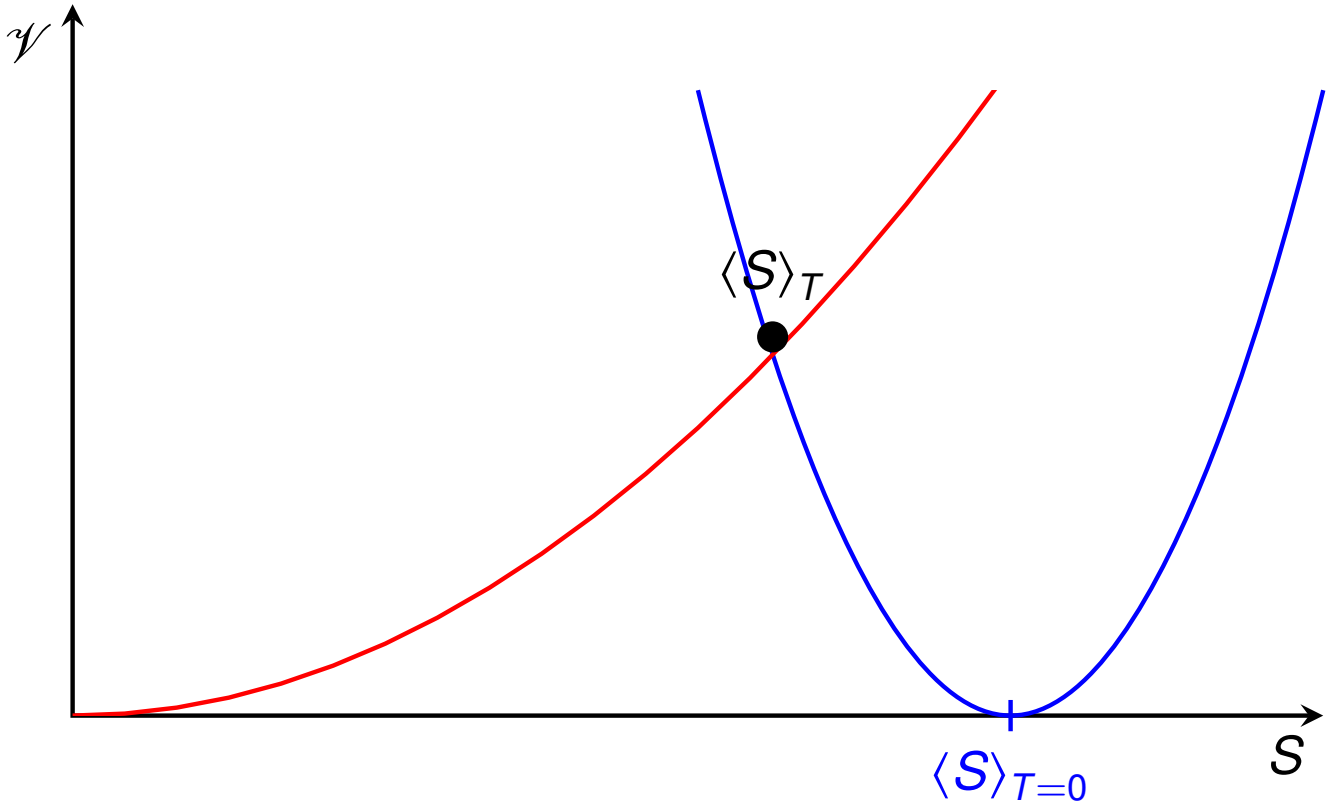

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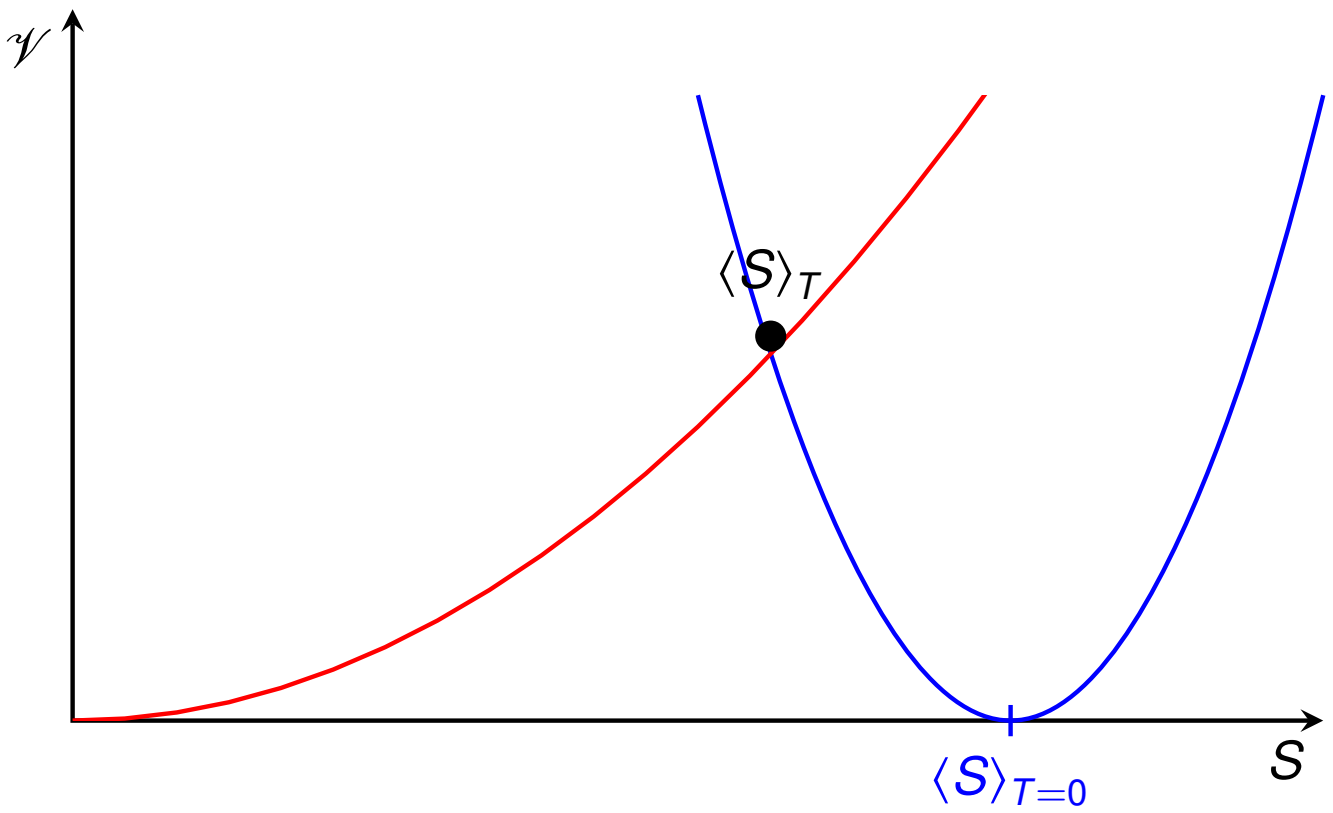

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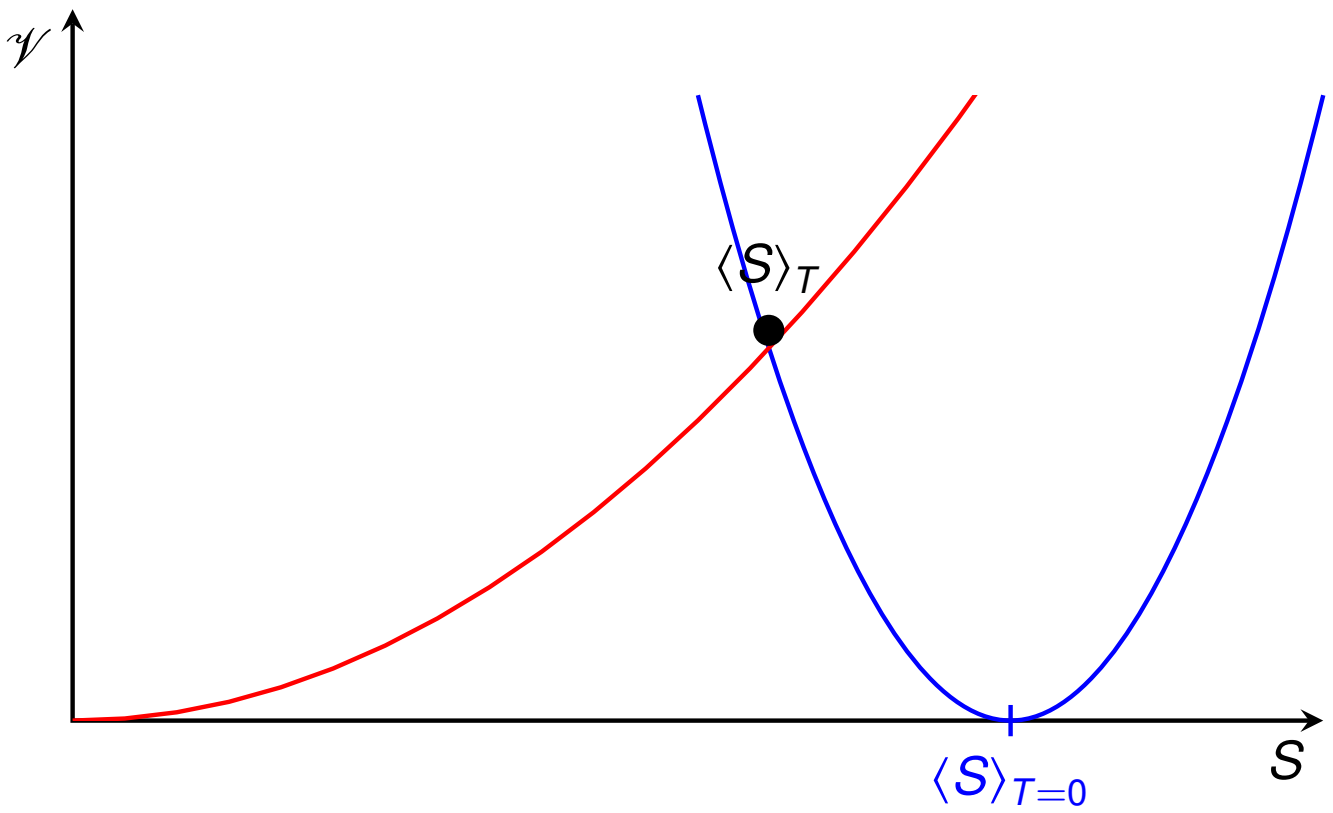

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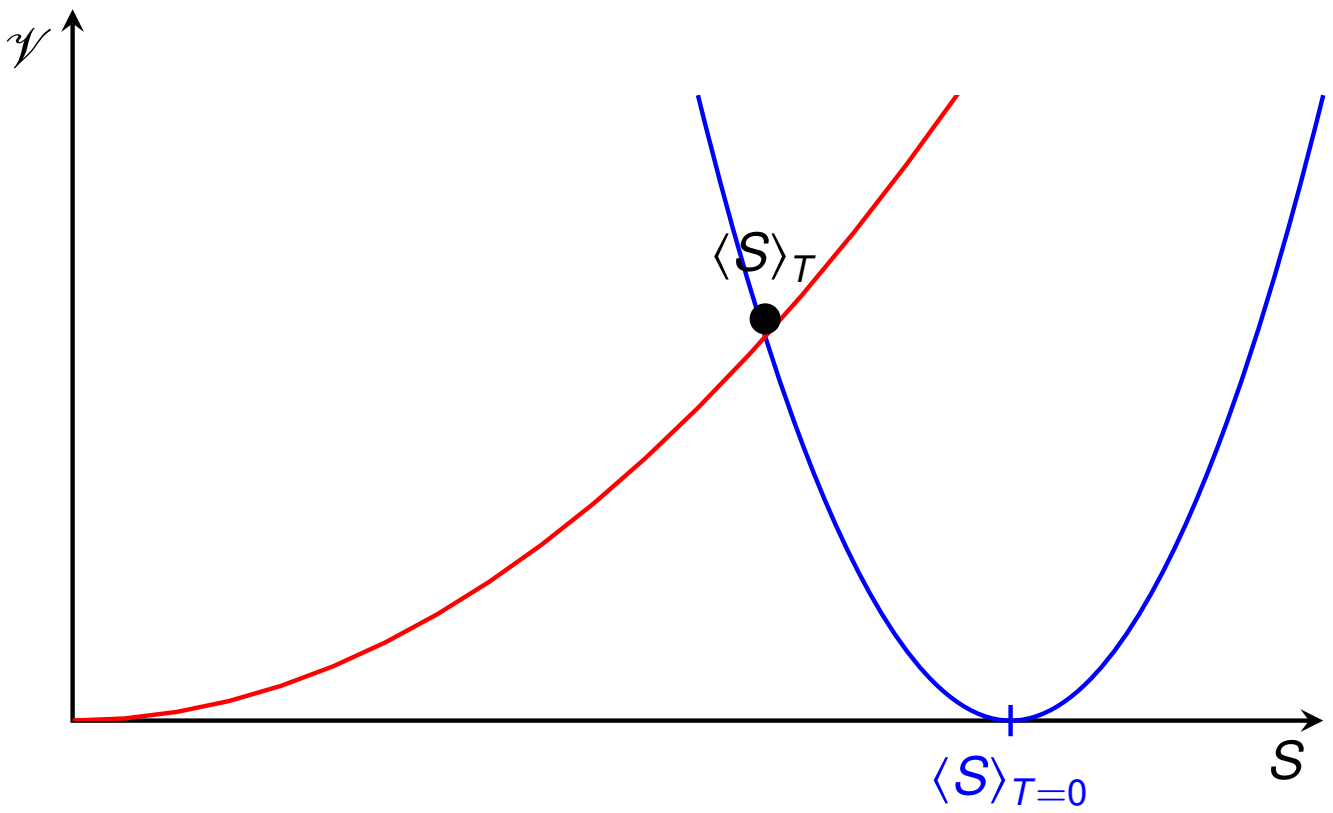

Dilaton destabilization

at

high temperature

Application 1: dilaton destabilization at high temperature

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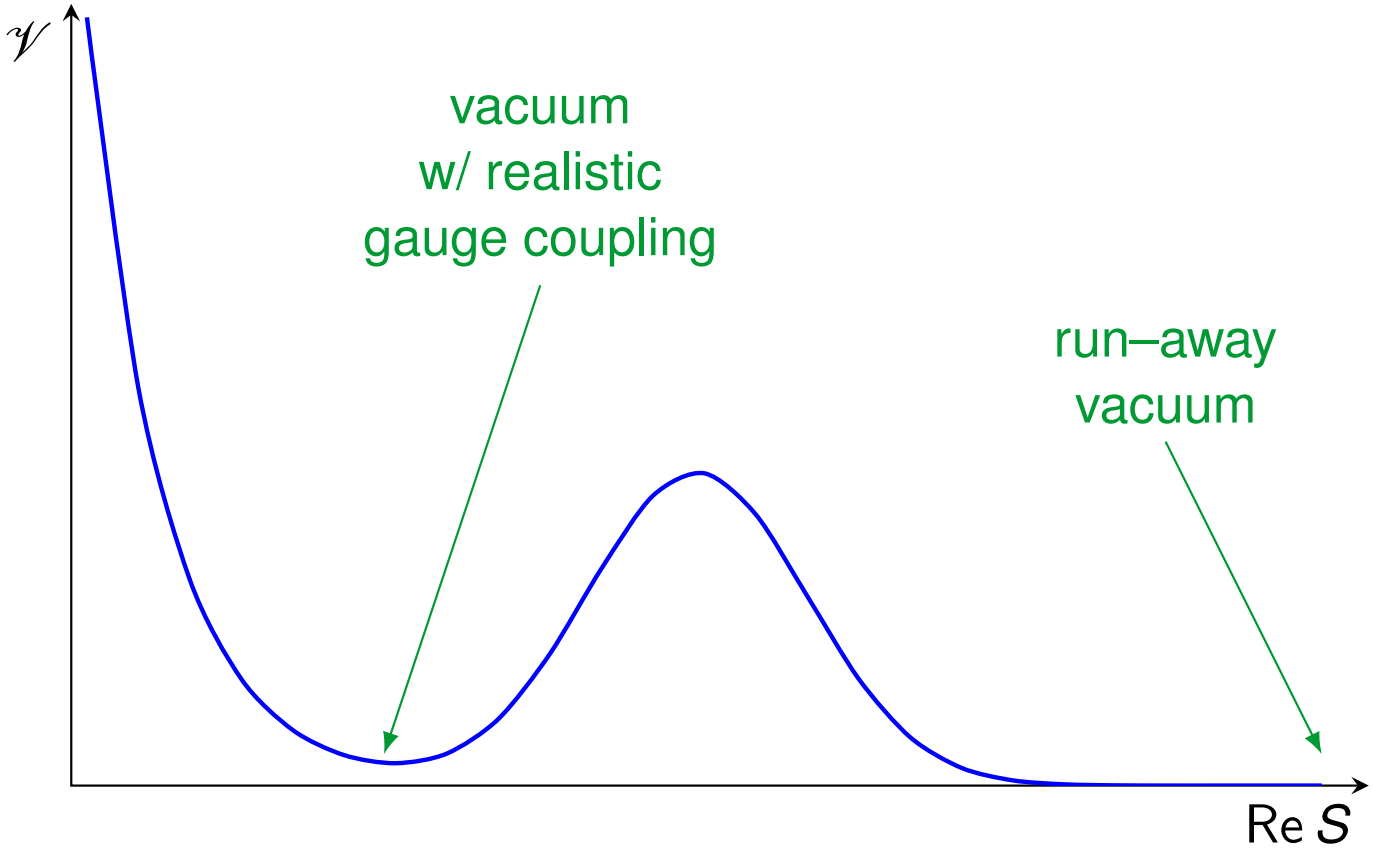
☞ typical moduli potential: $g^2 = 1/(\mathrm{Re}\, S)$



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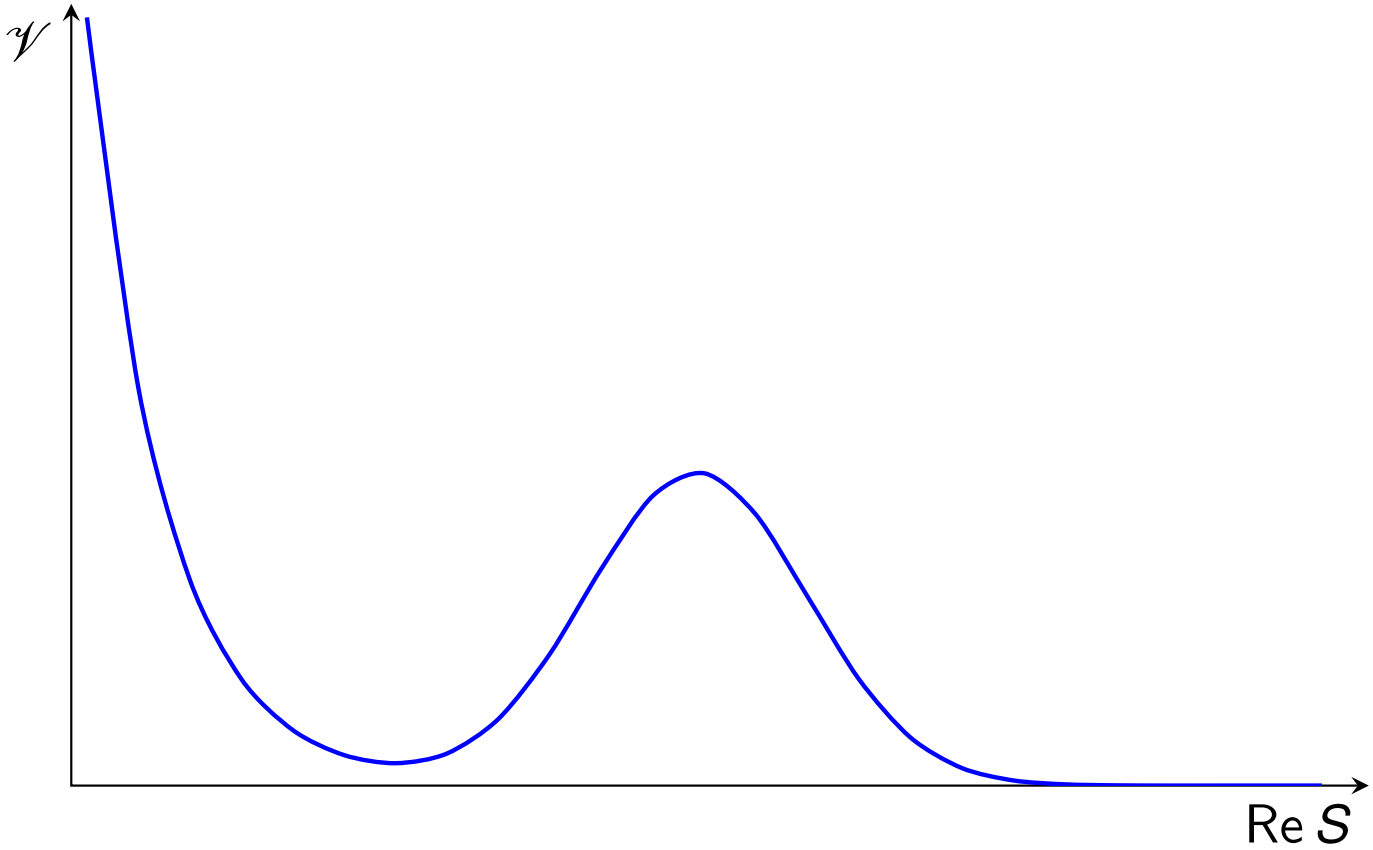

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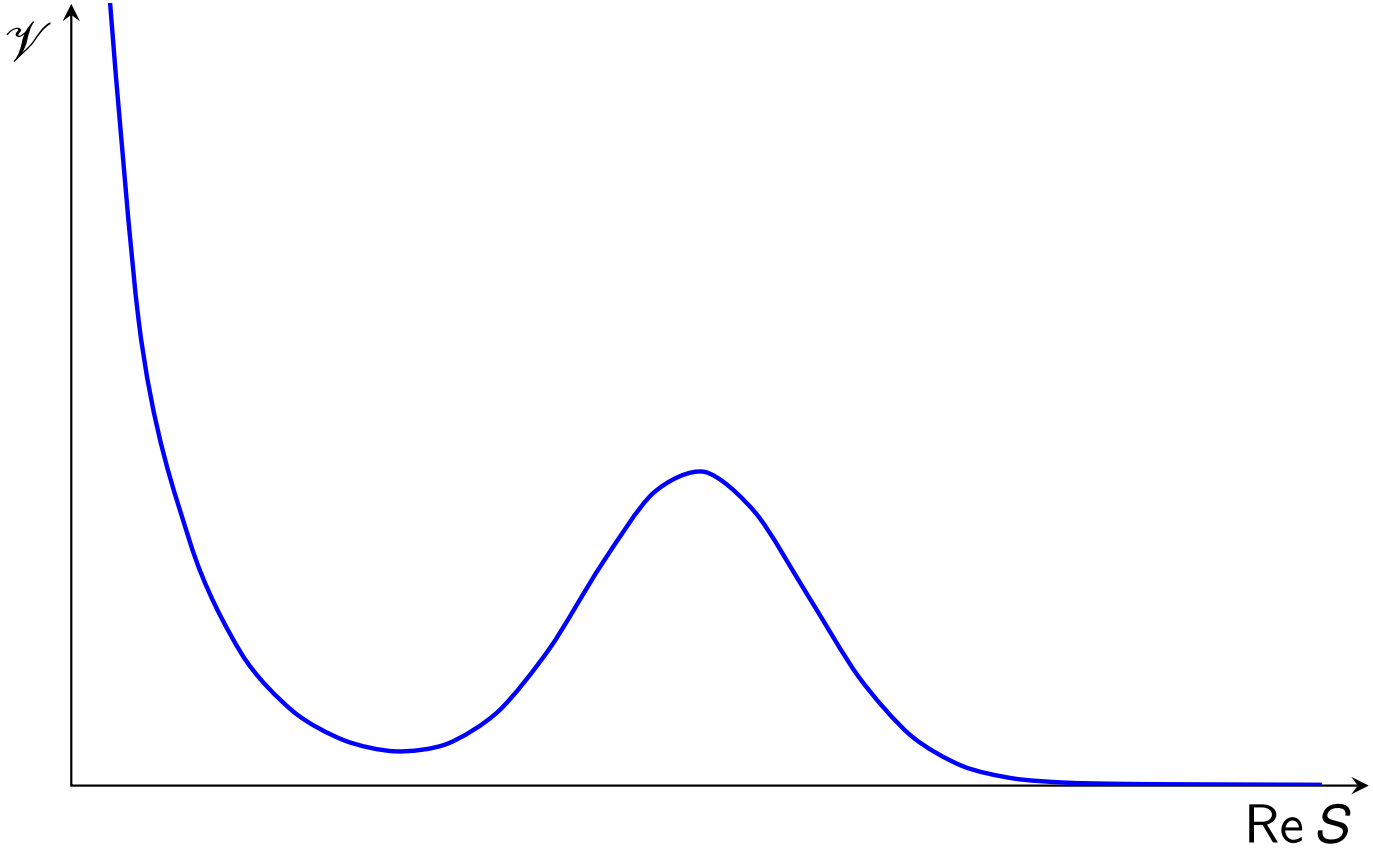

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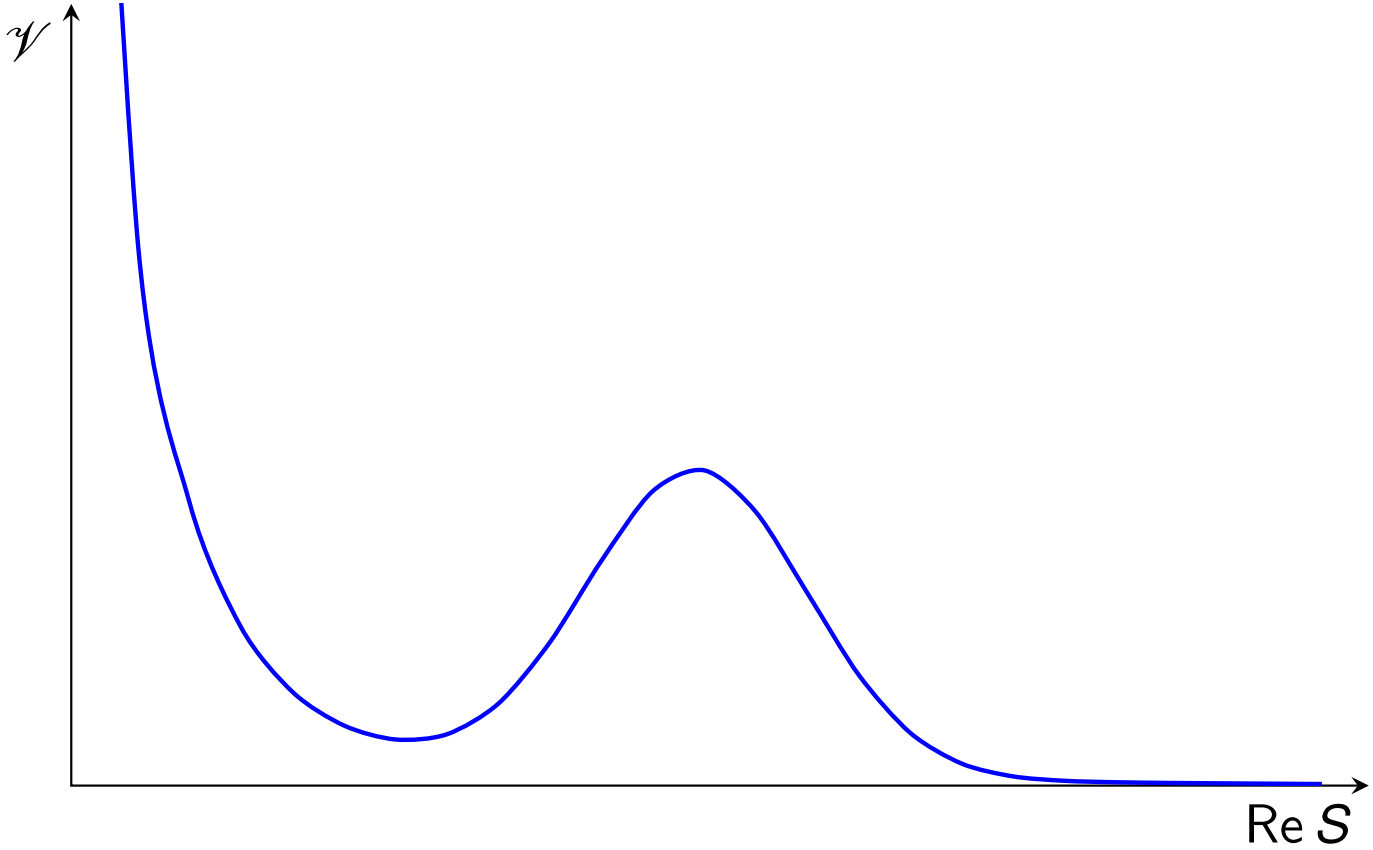

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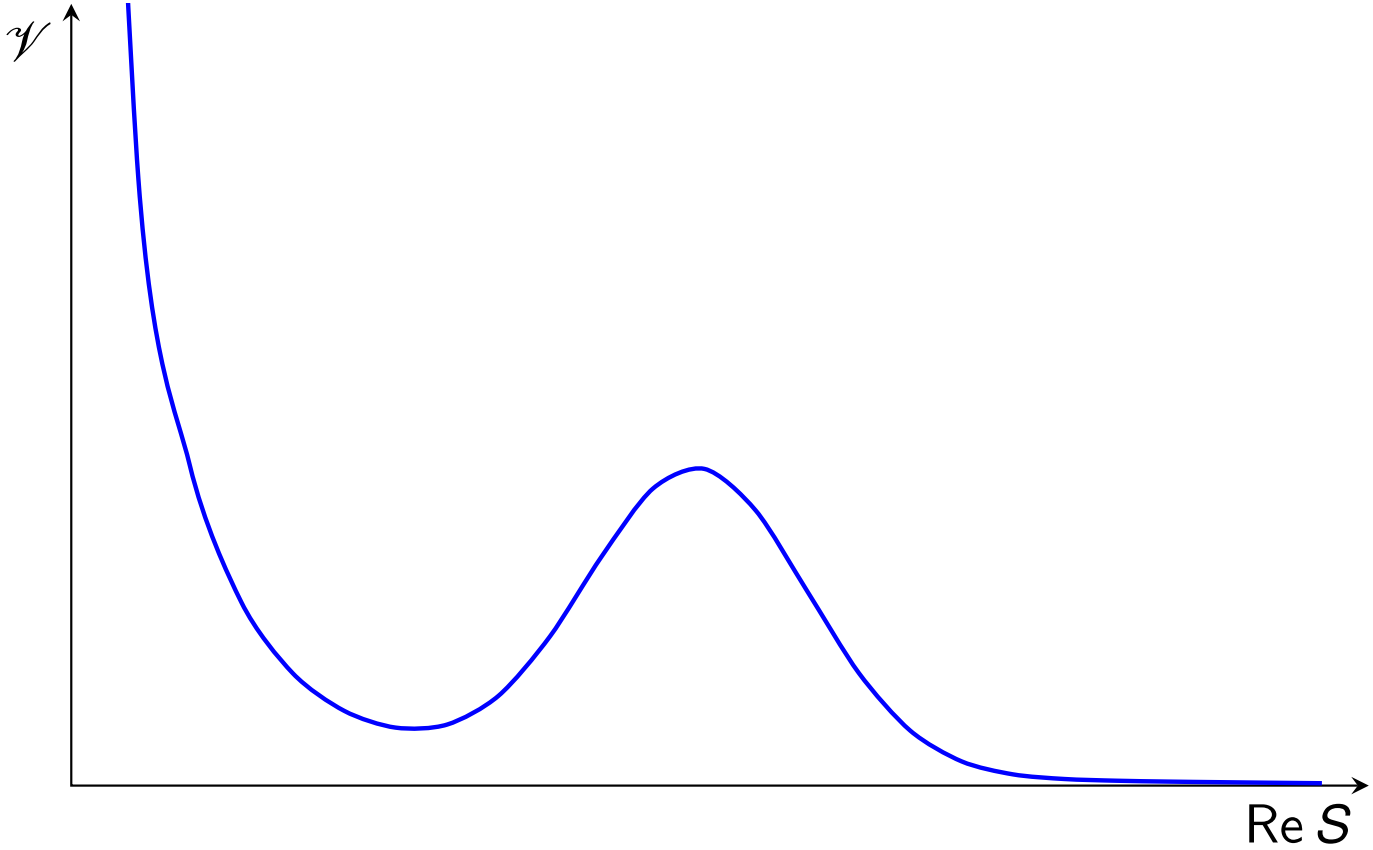

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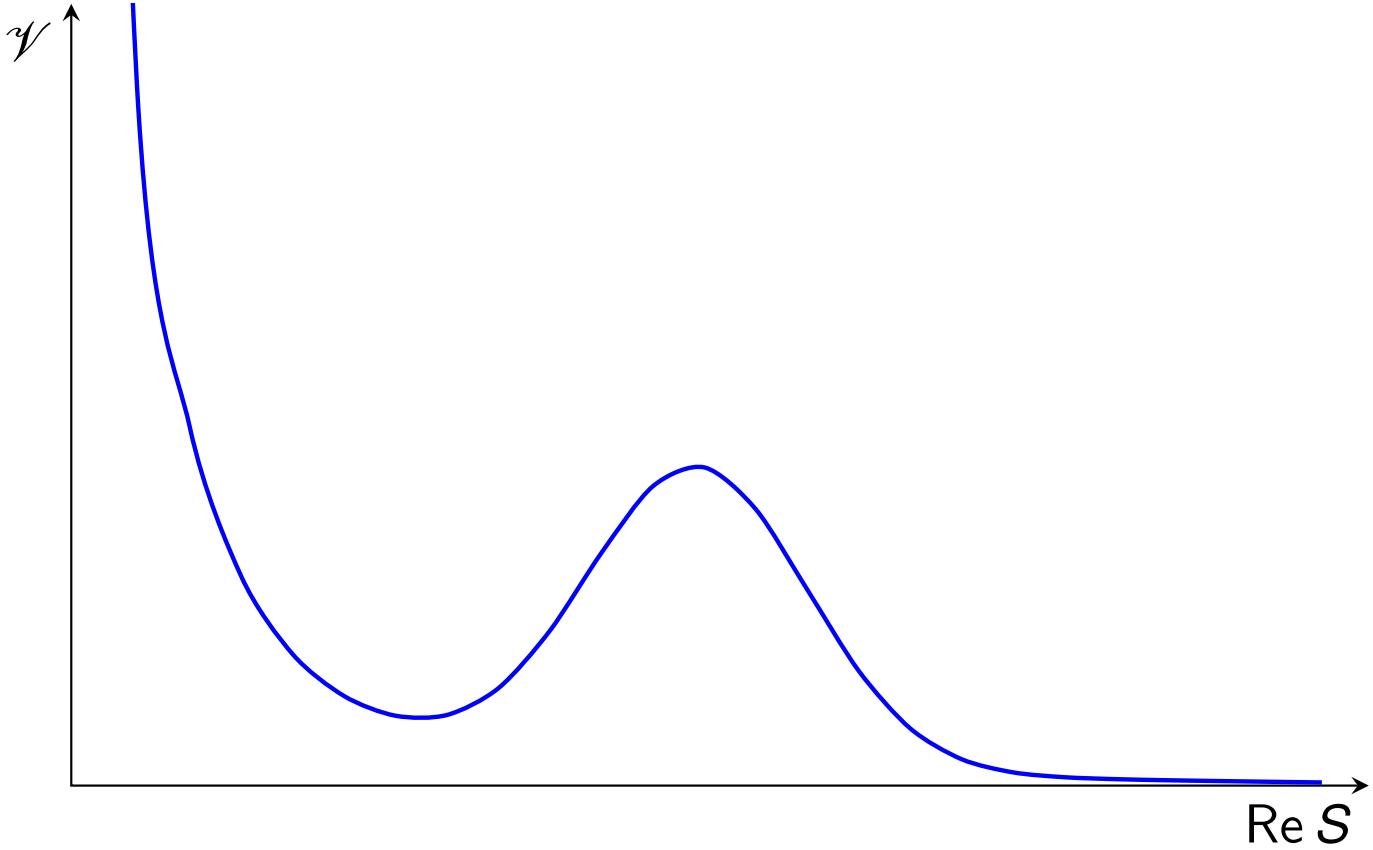

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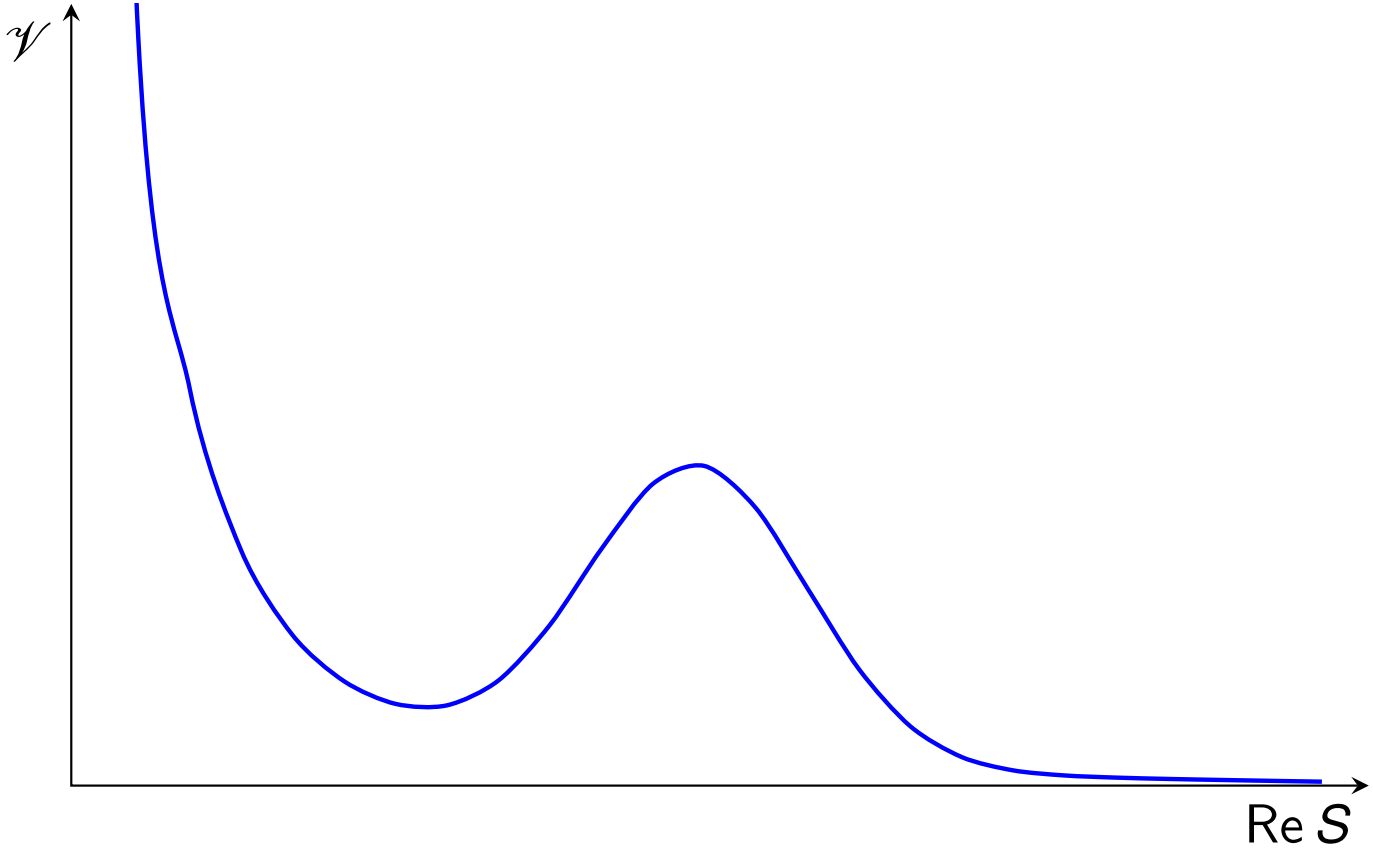

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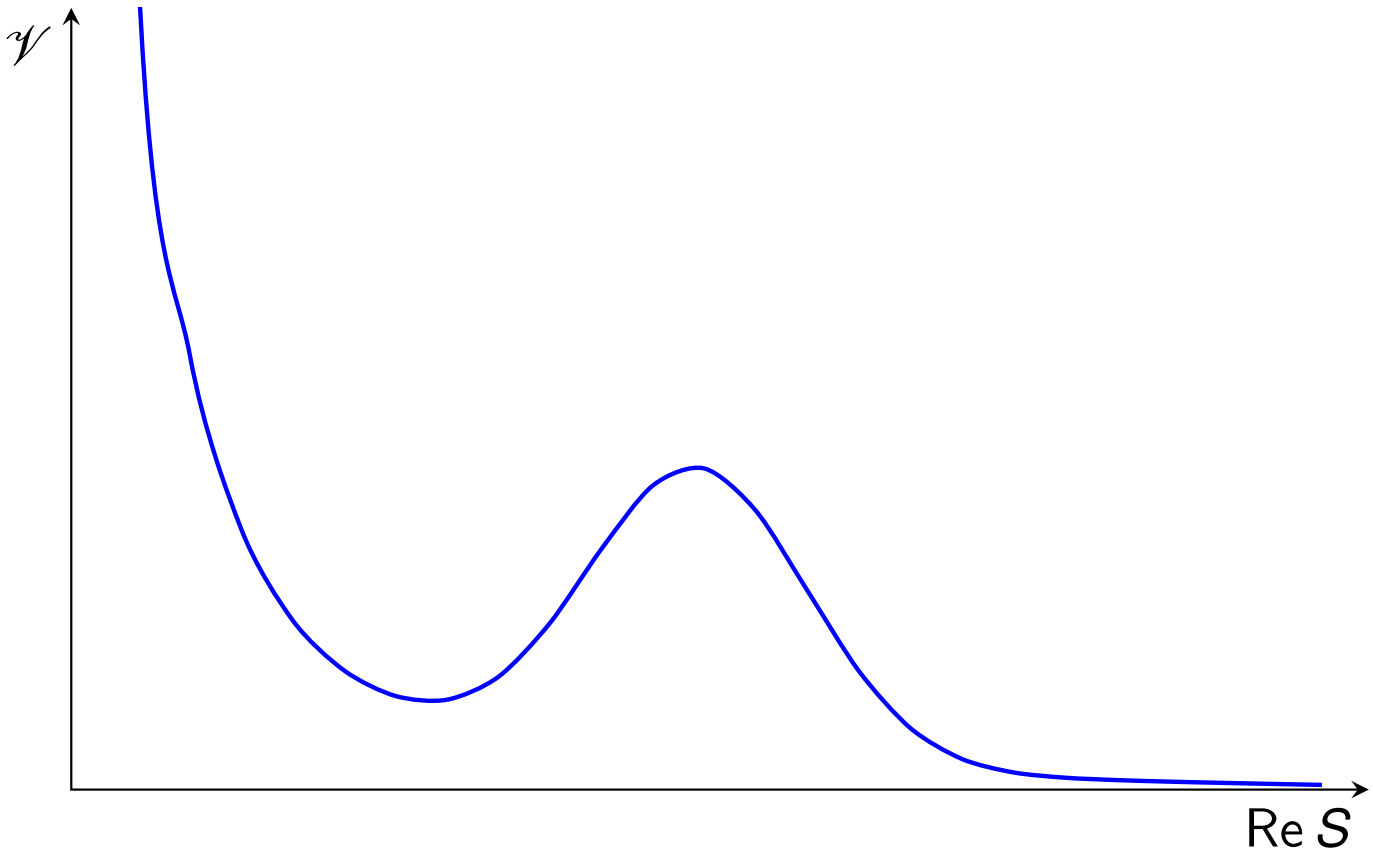

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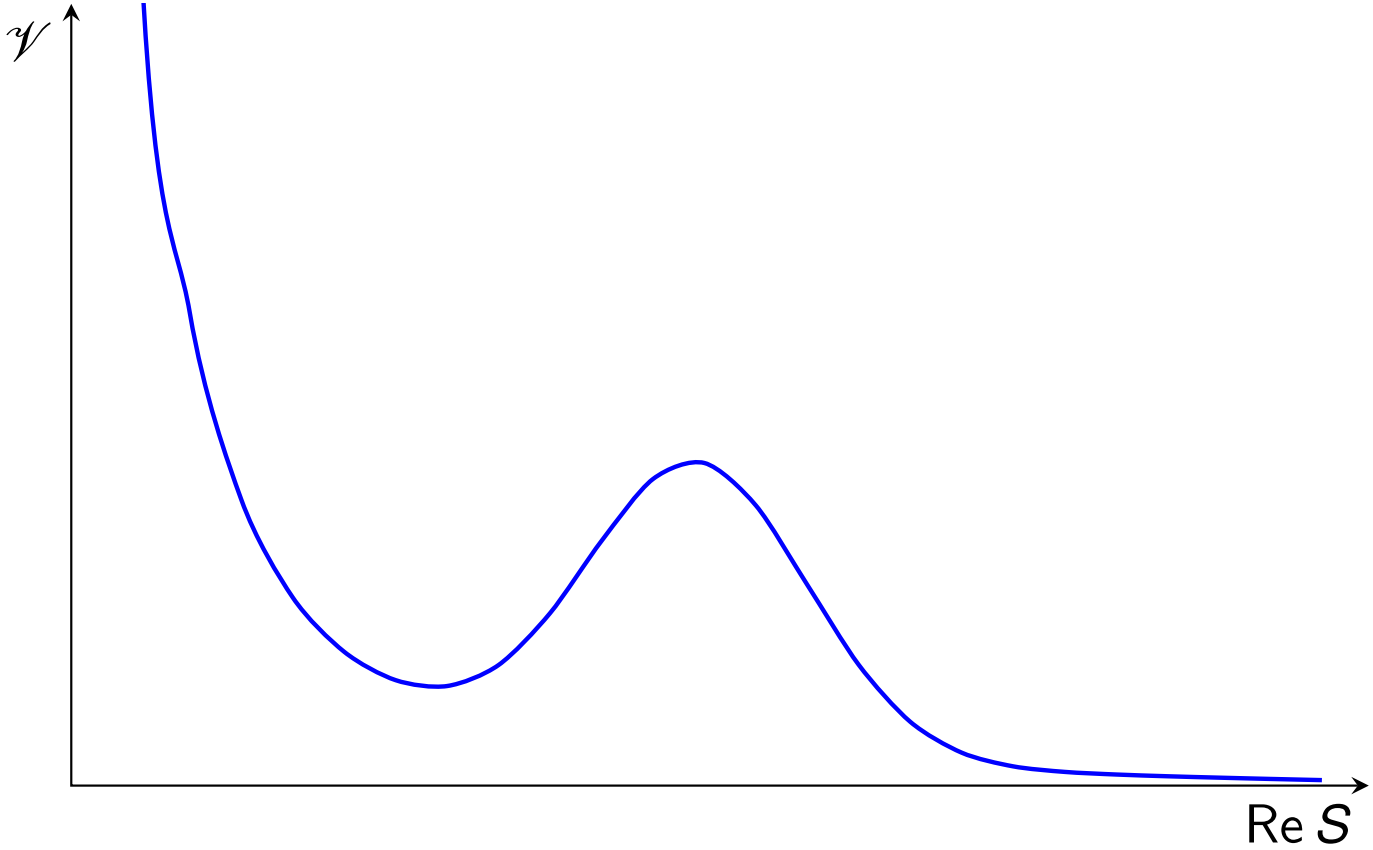

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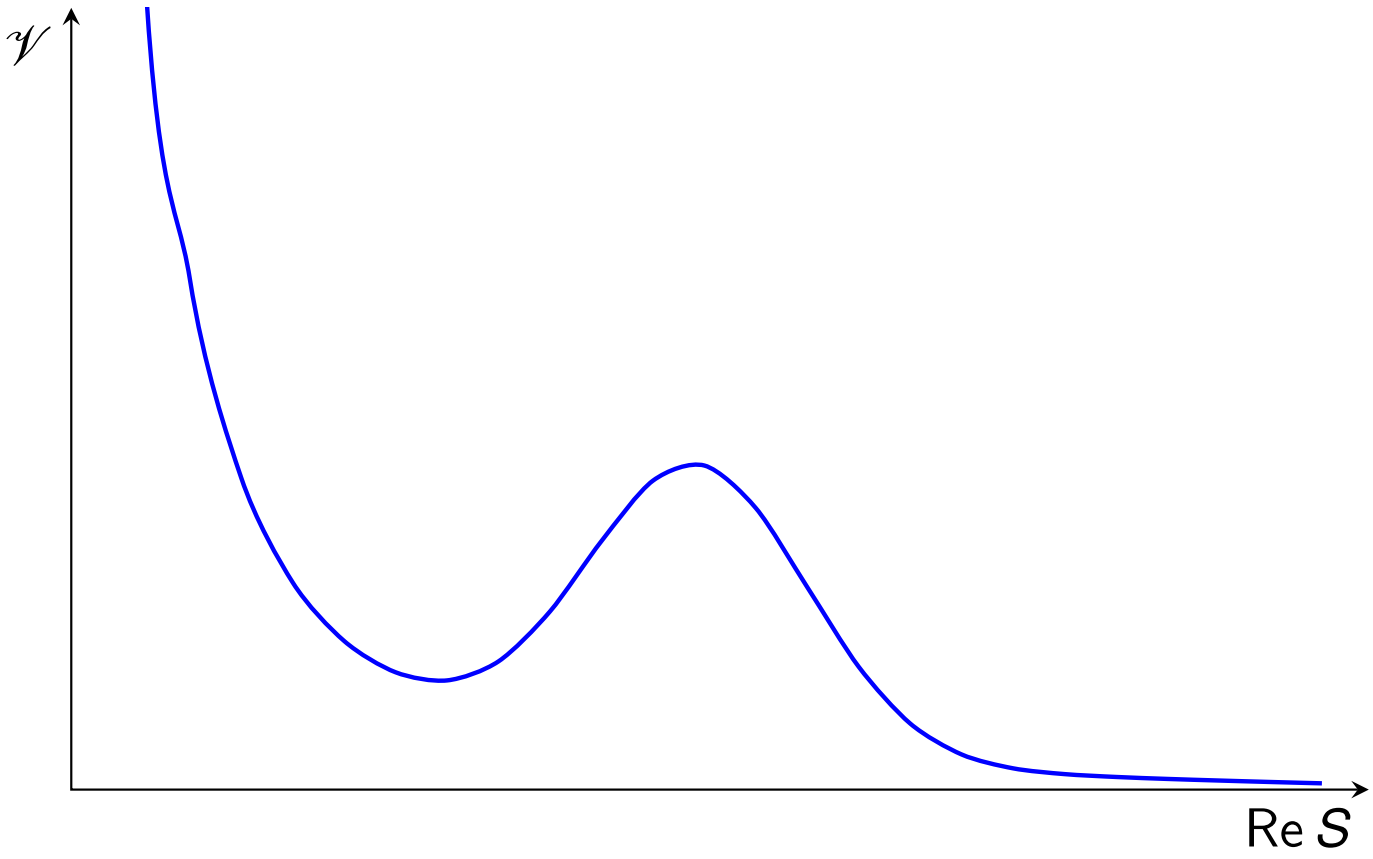

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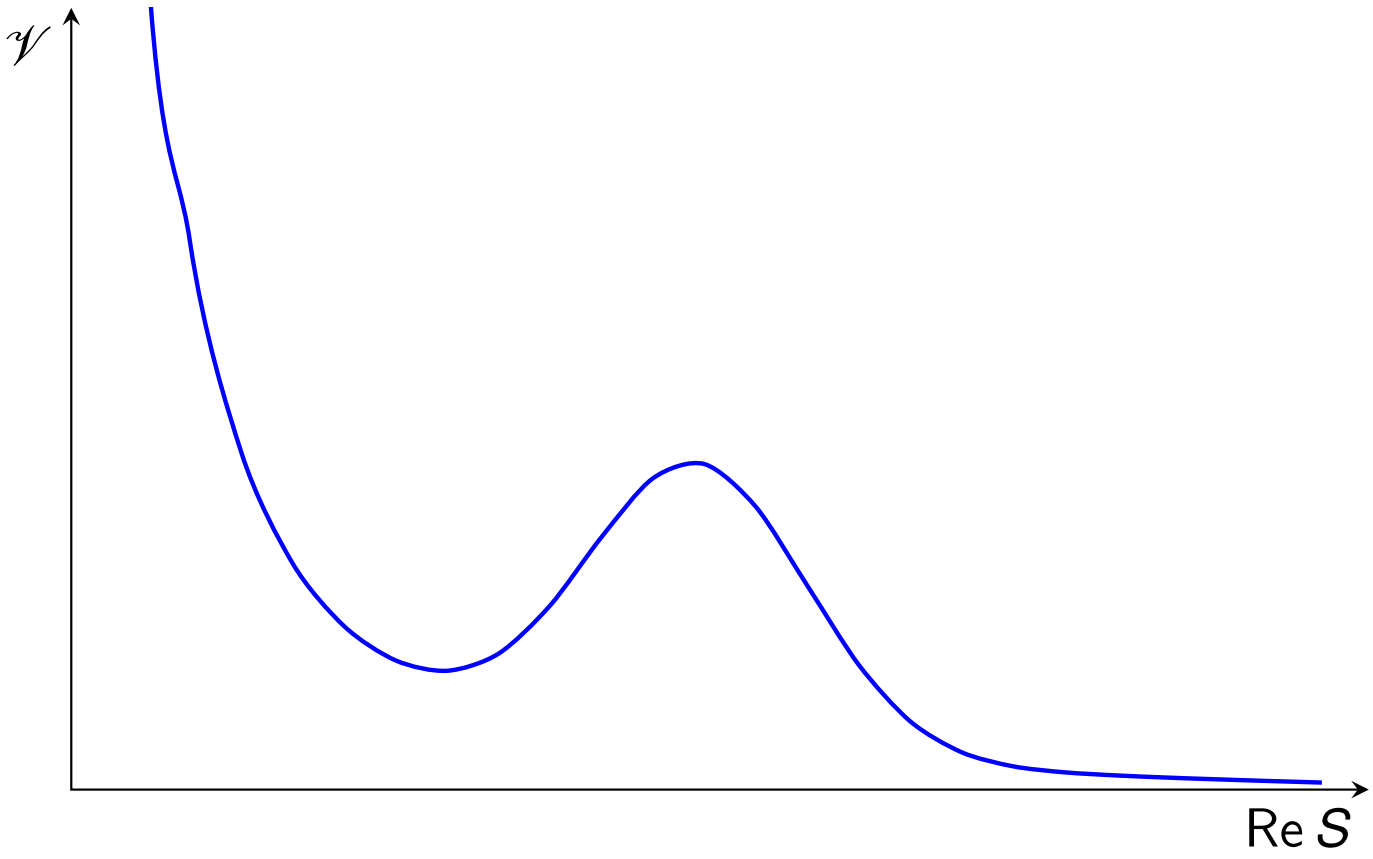

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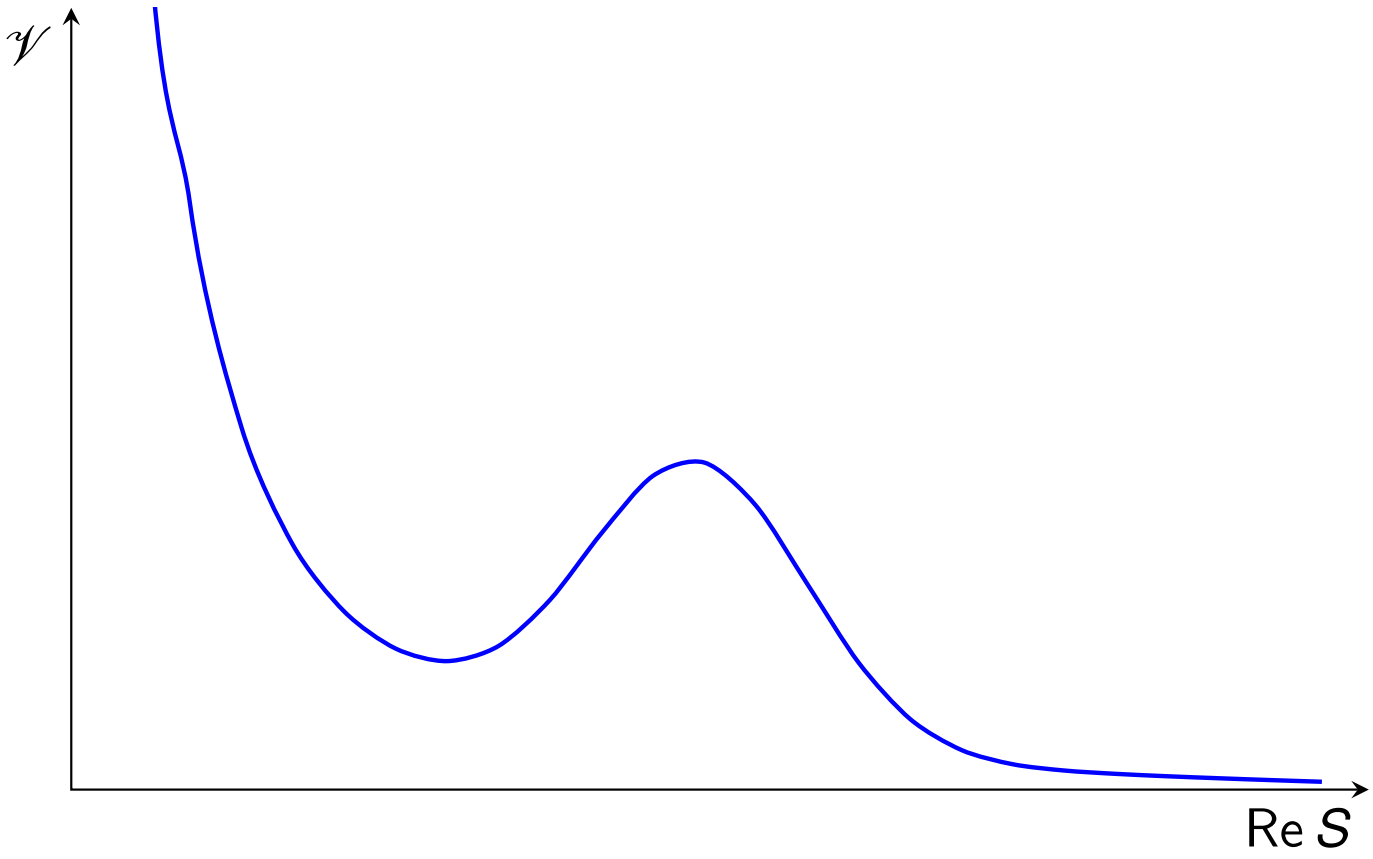

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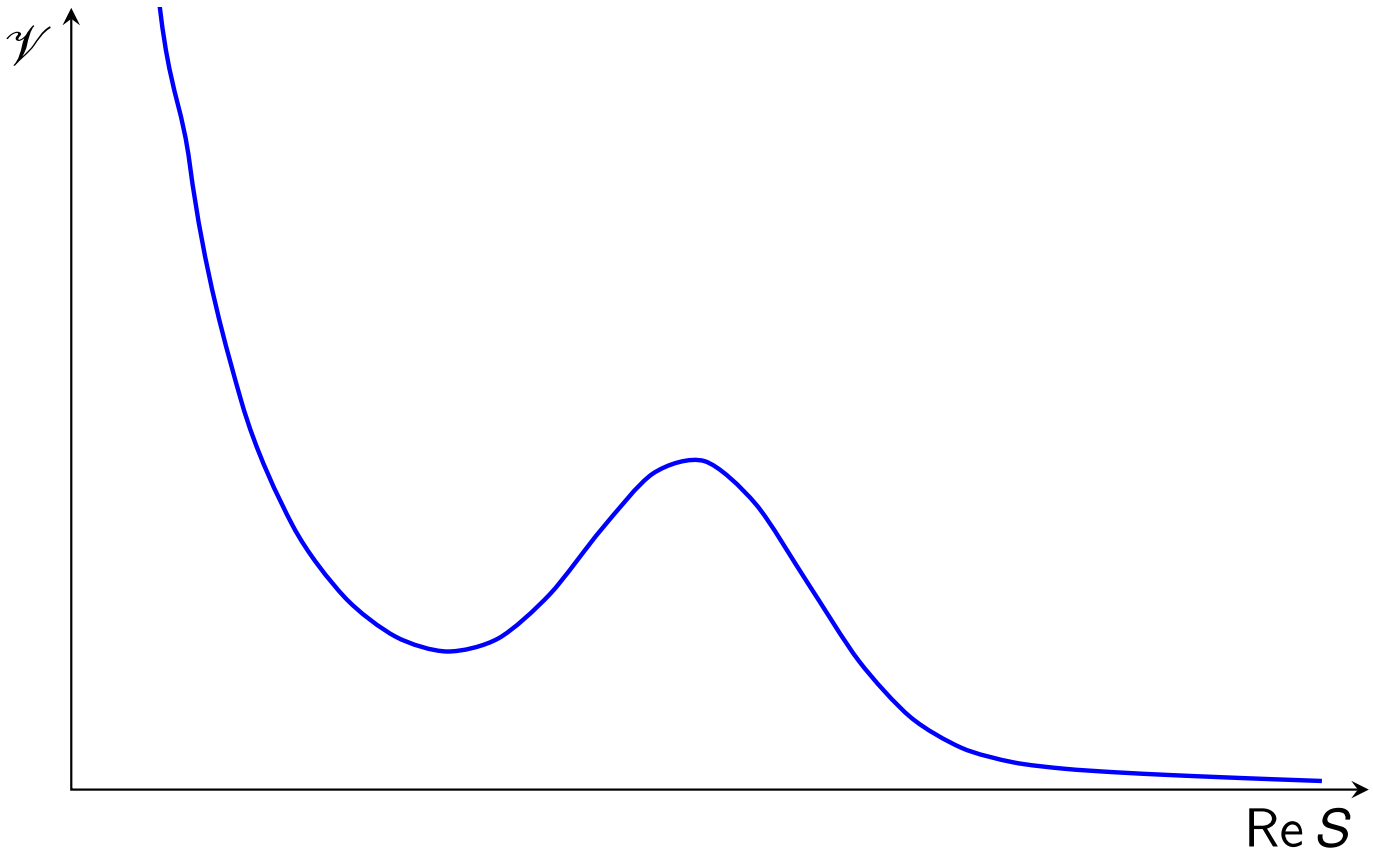

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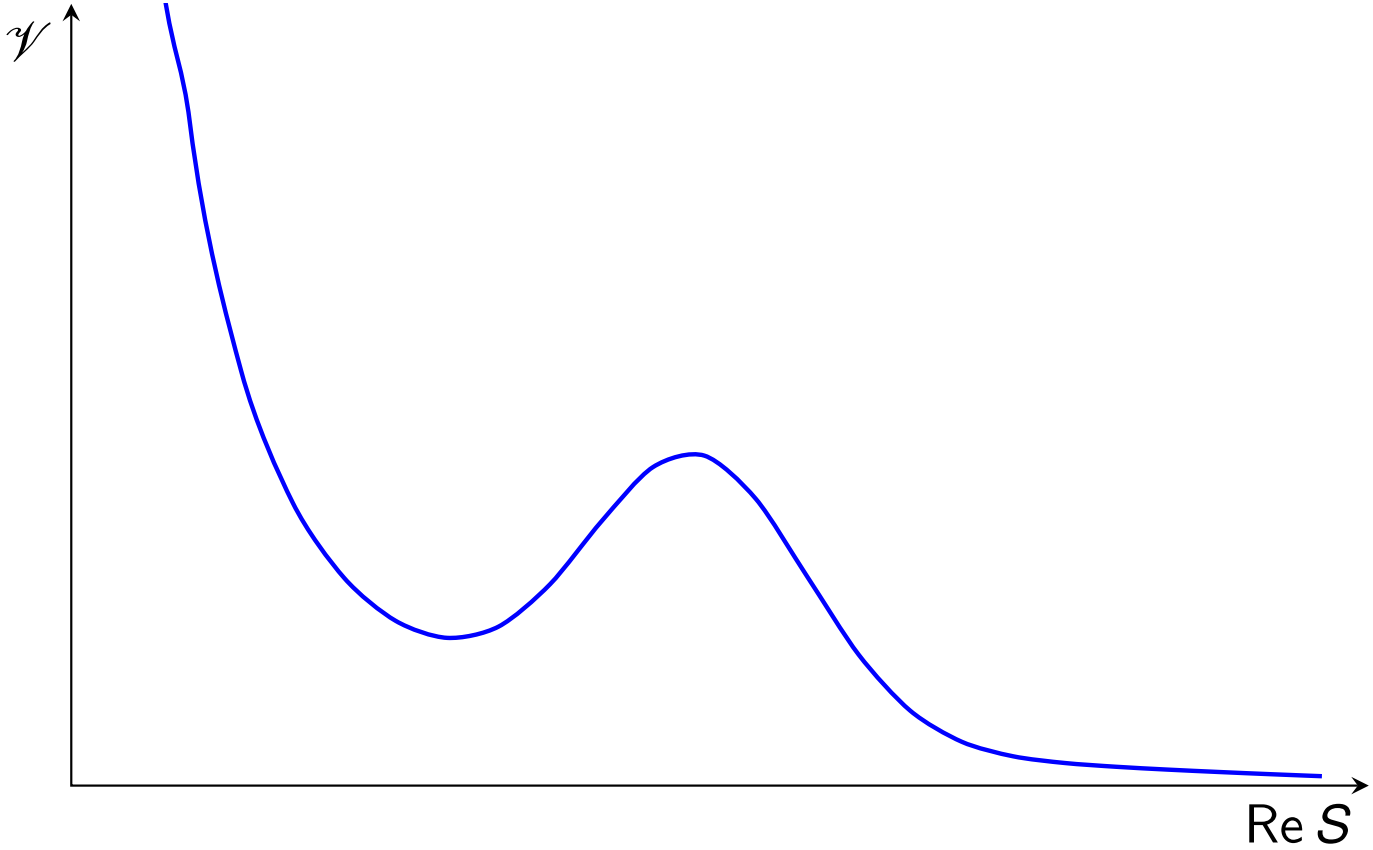

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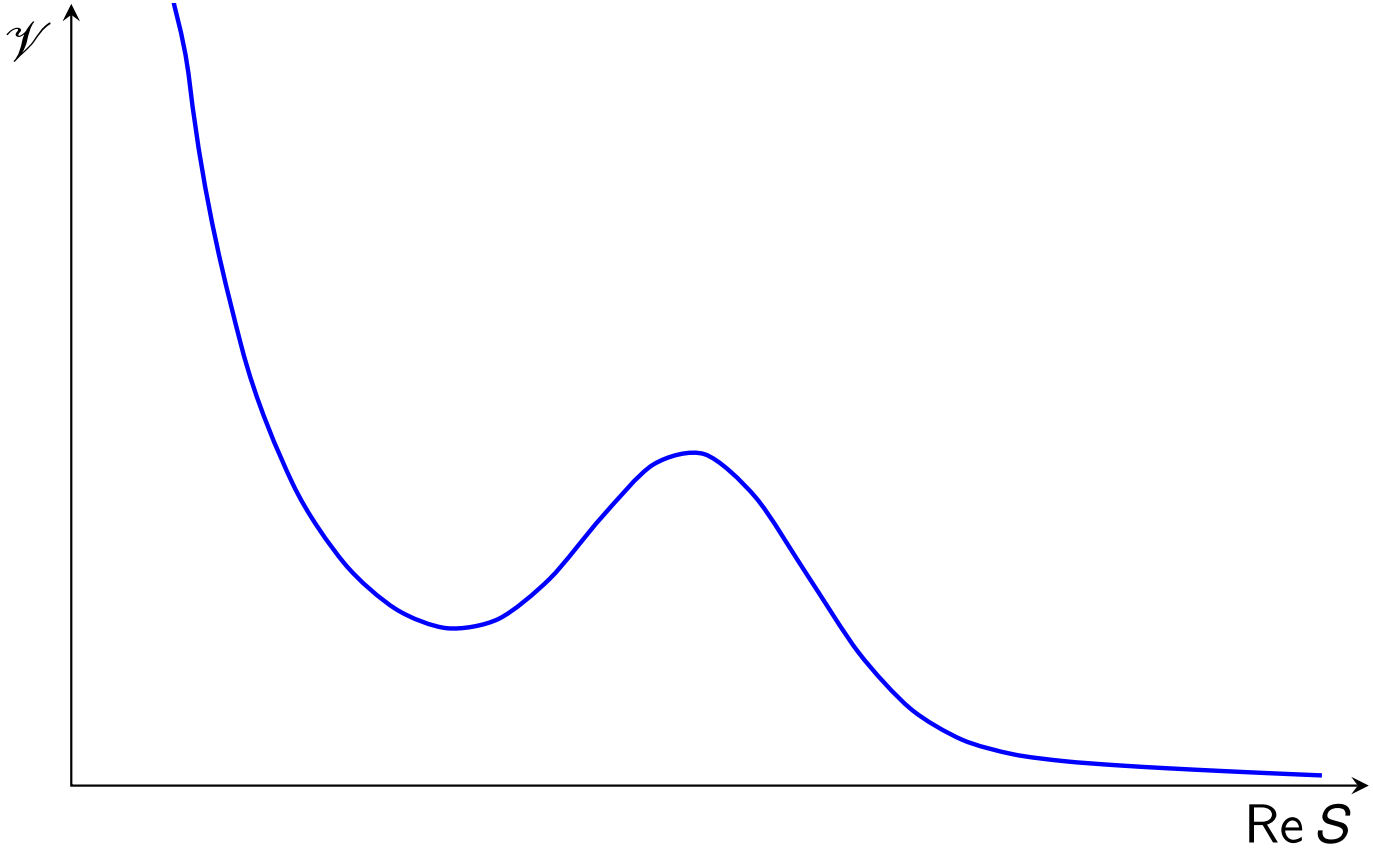

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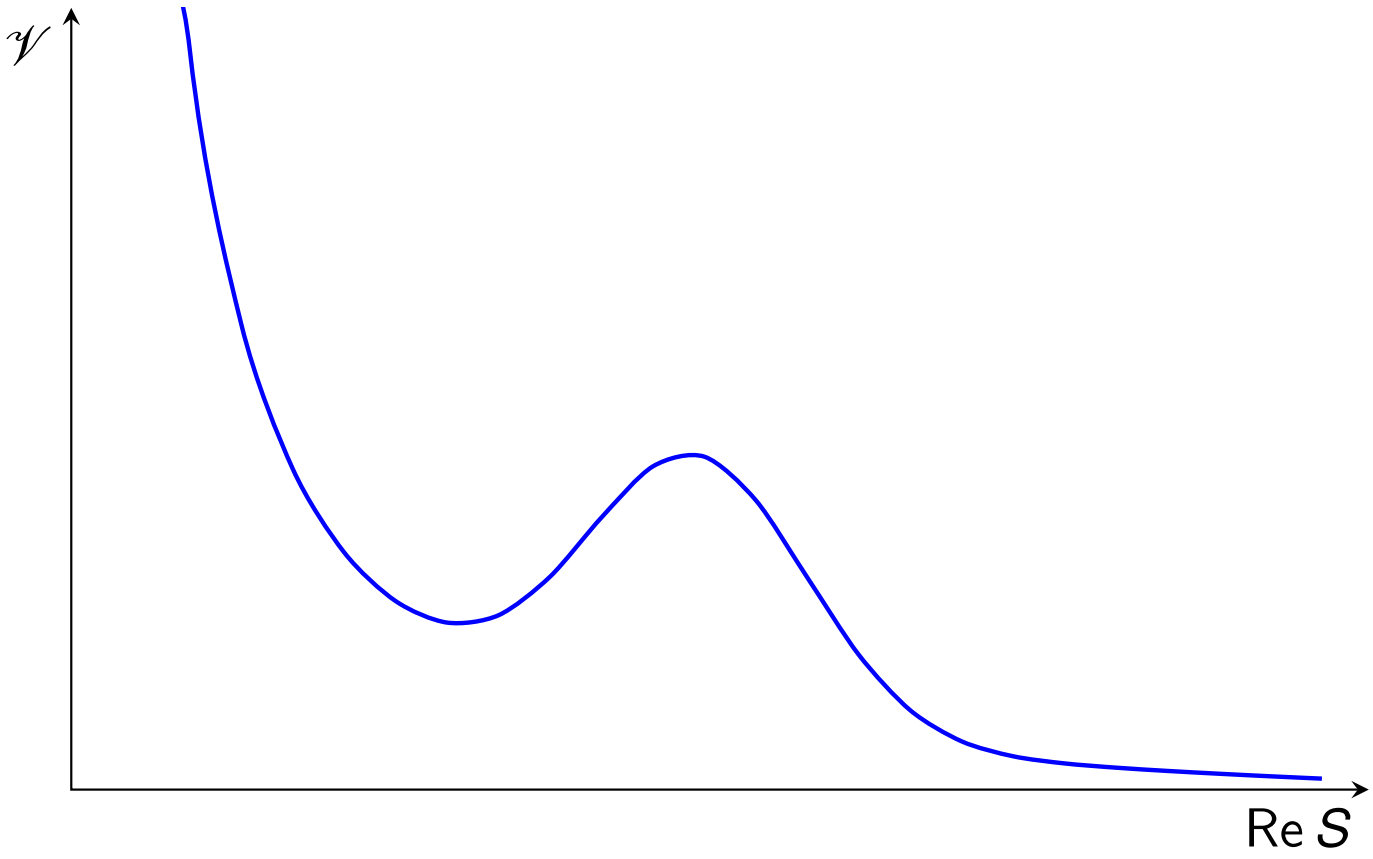

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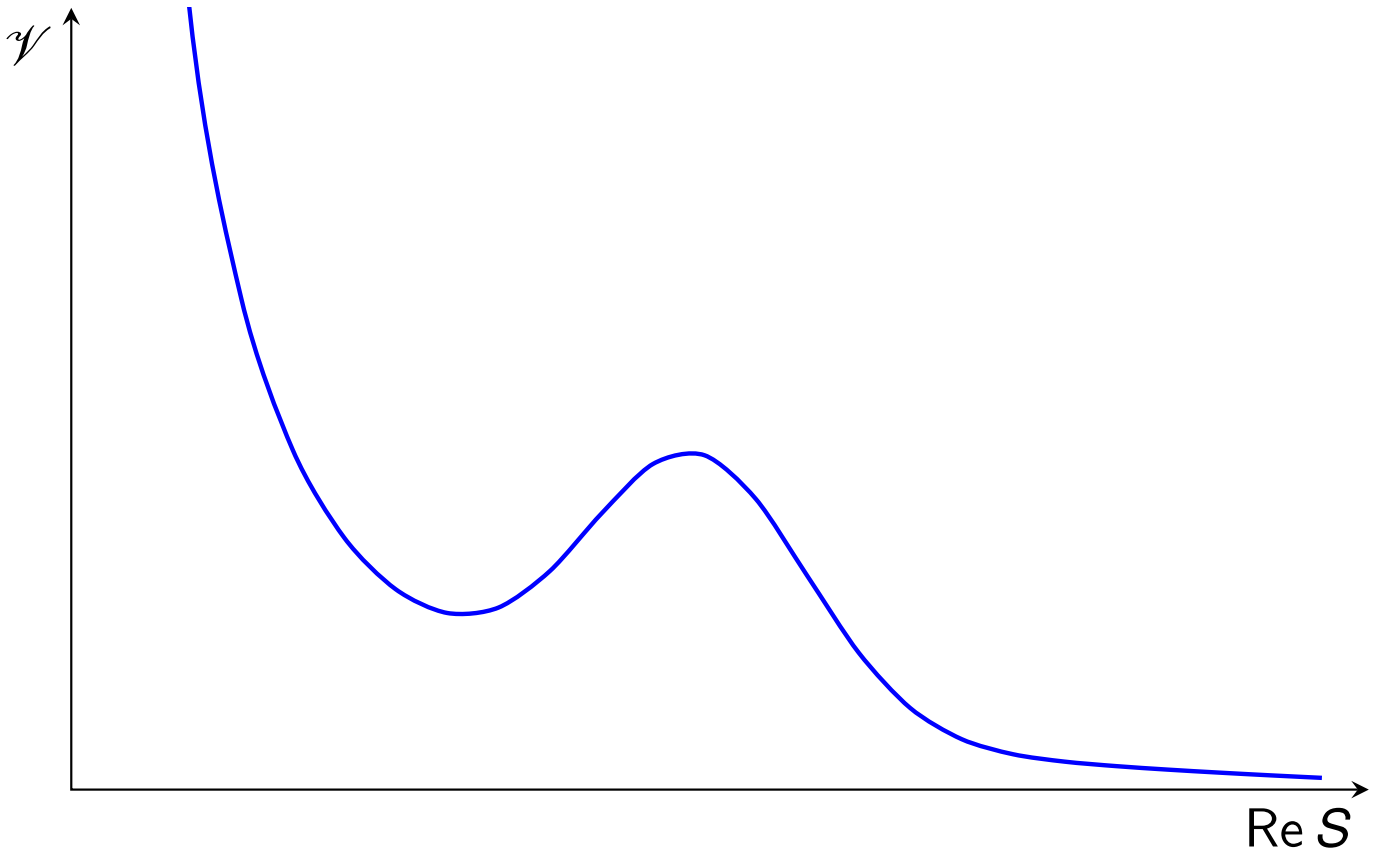

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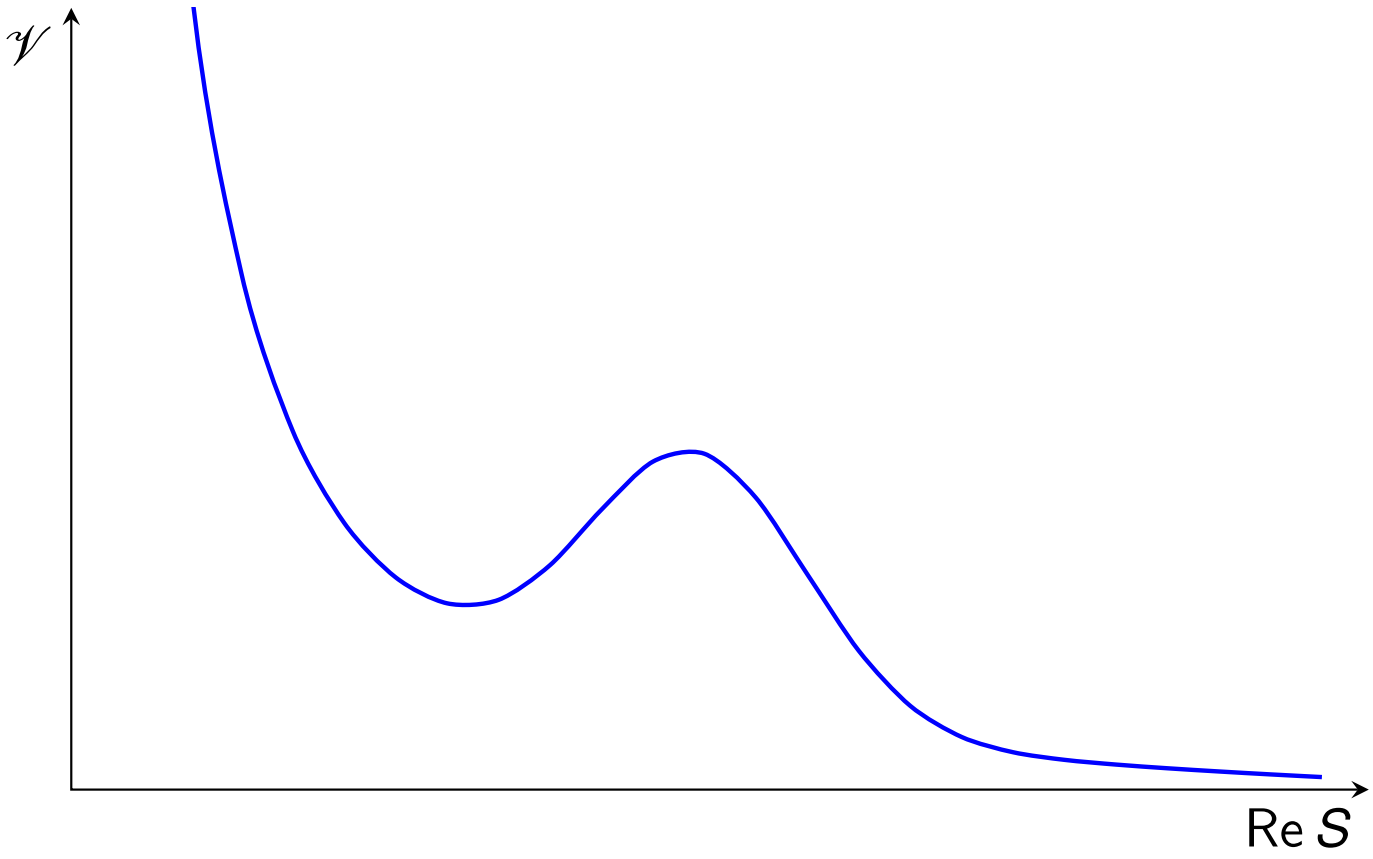

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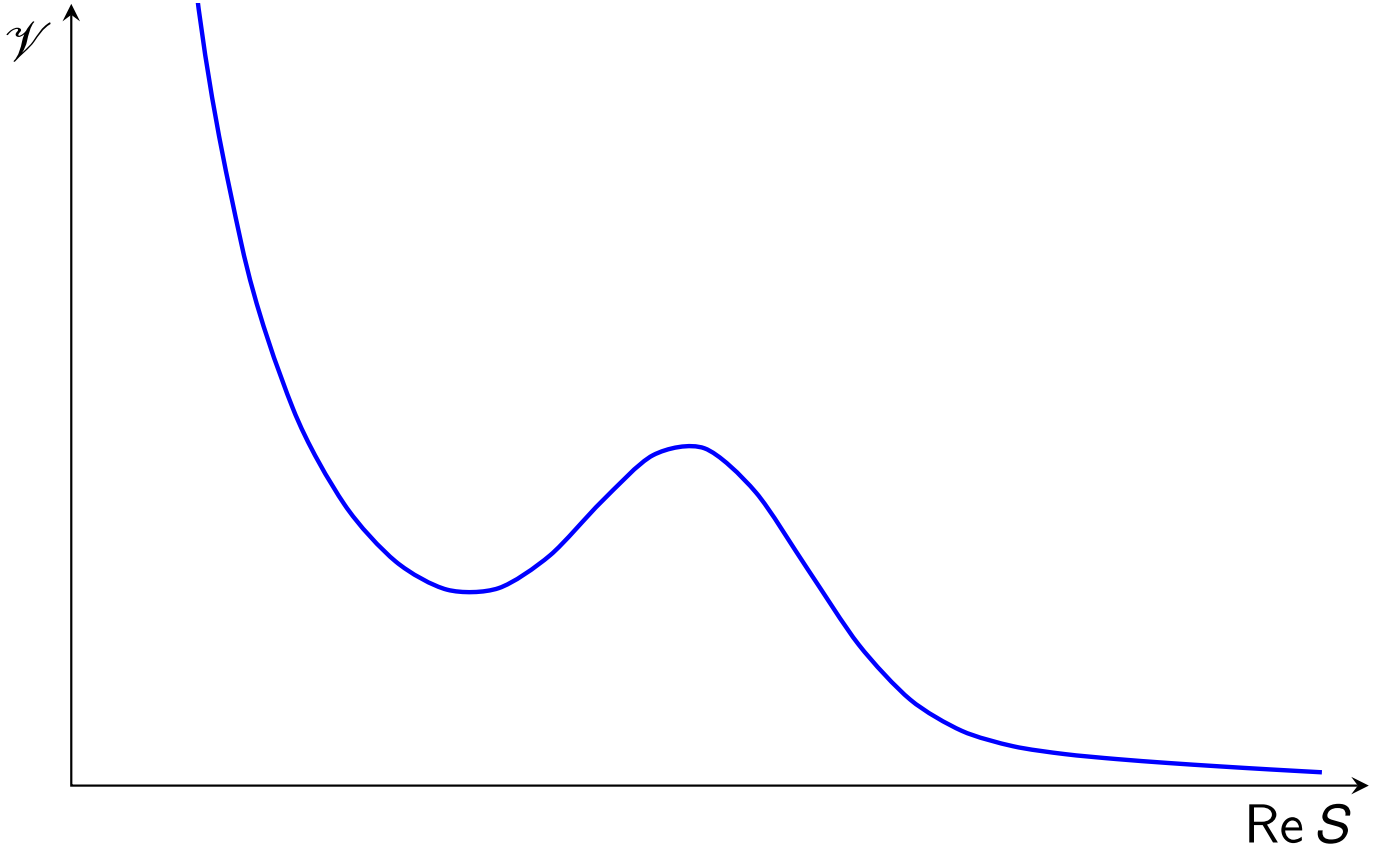

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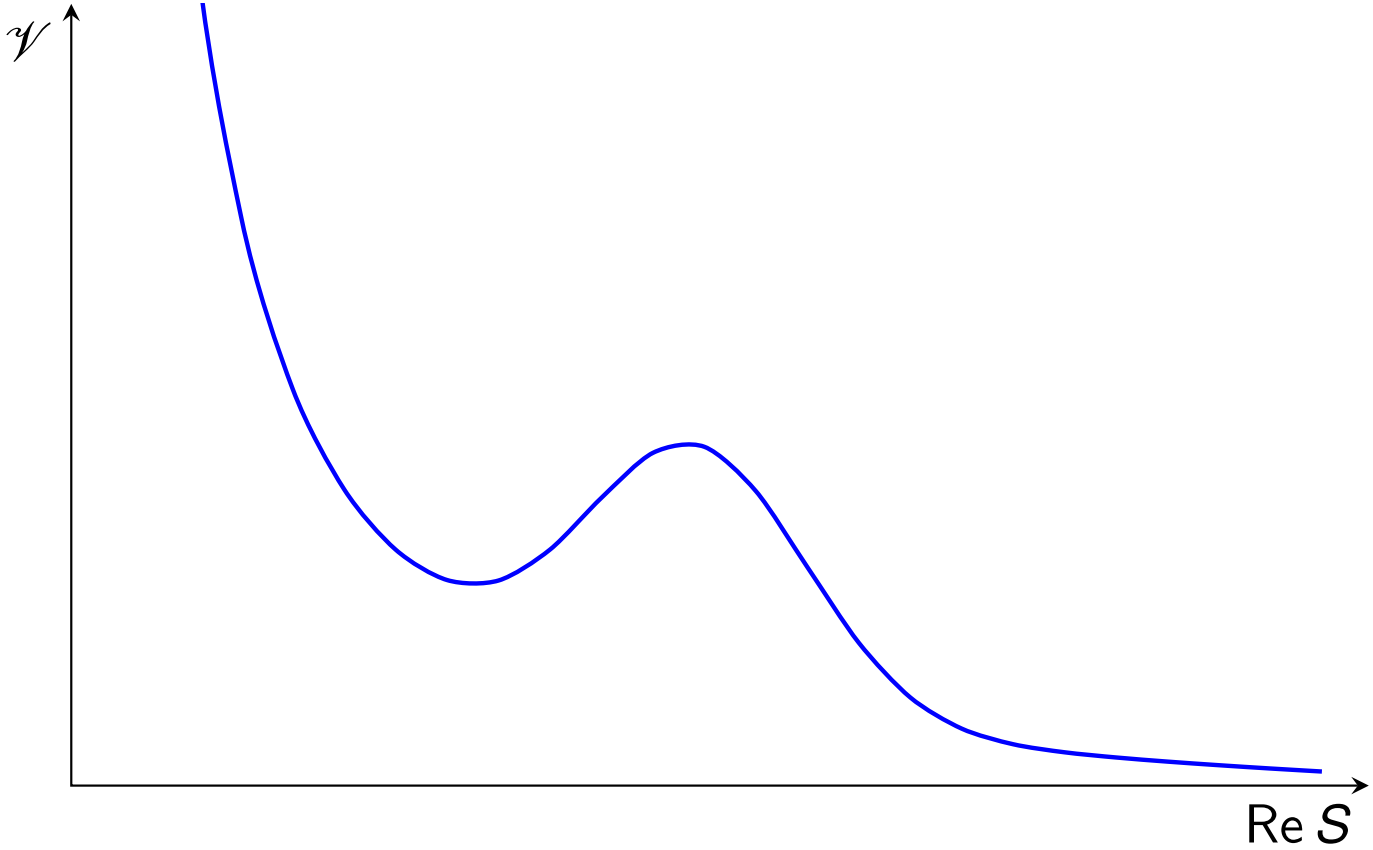

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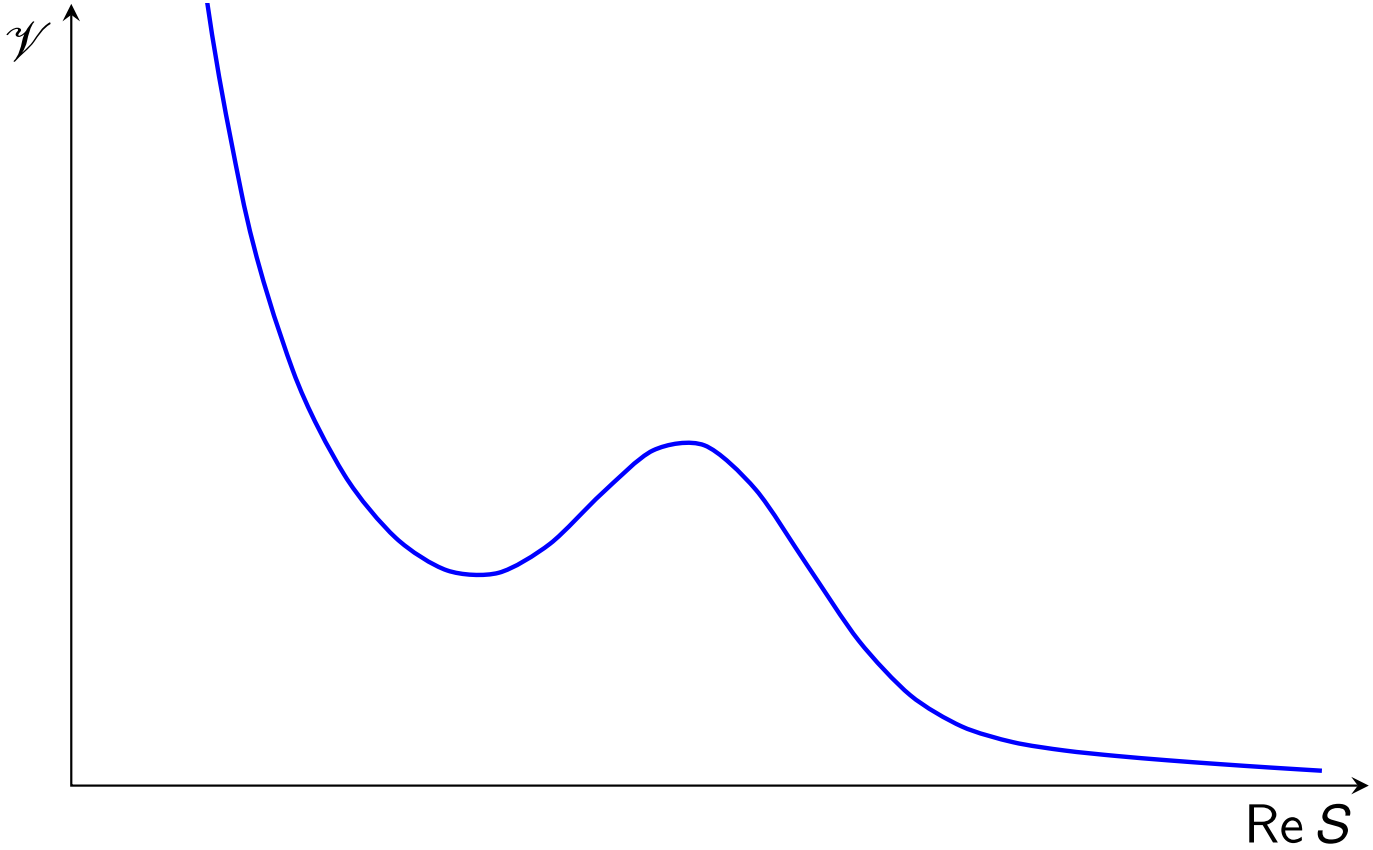

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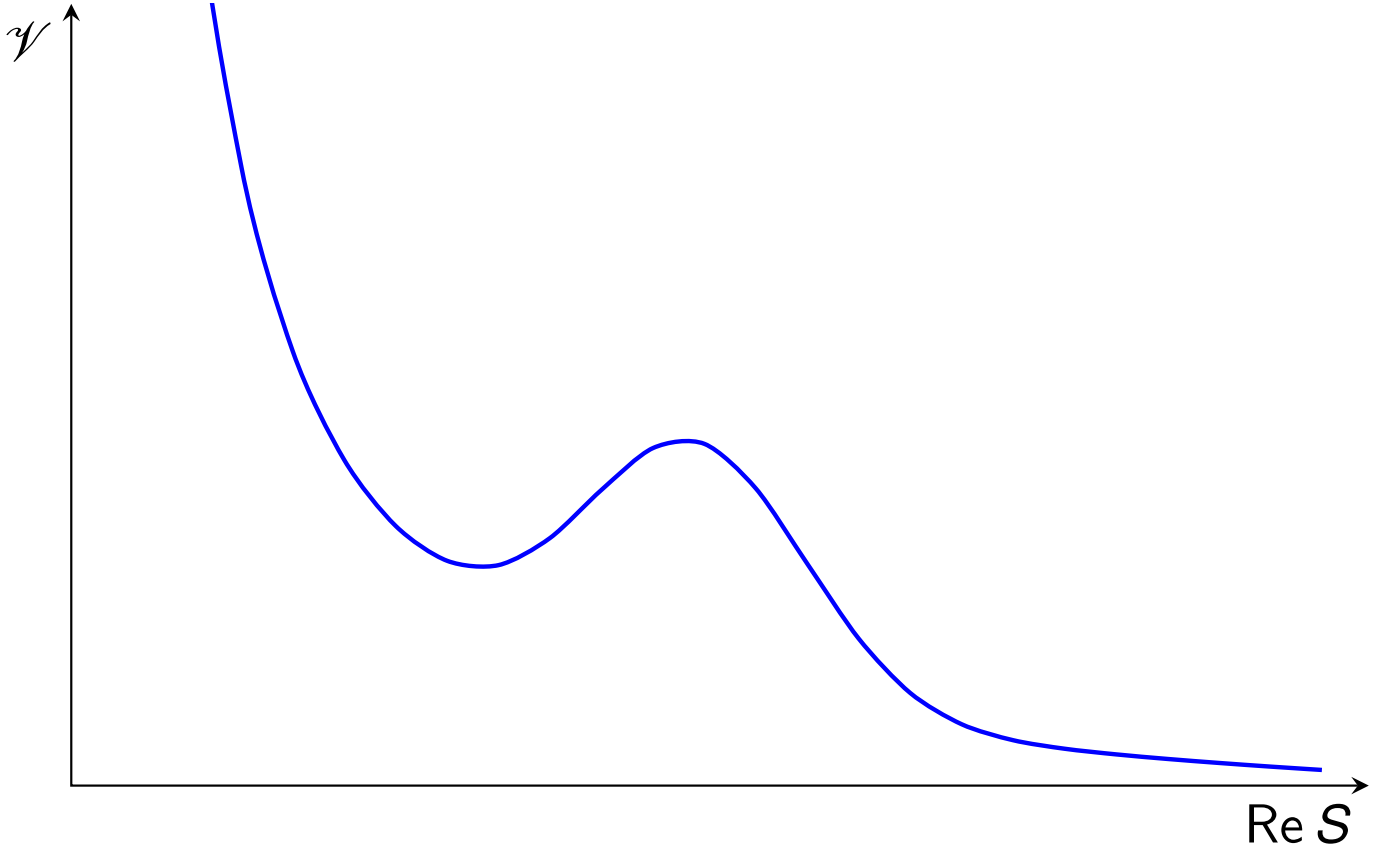

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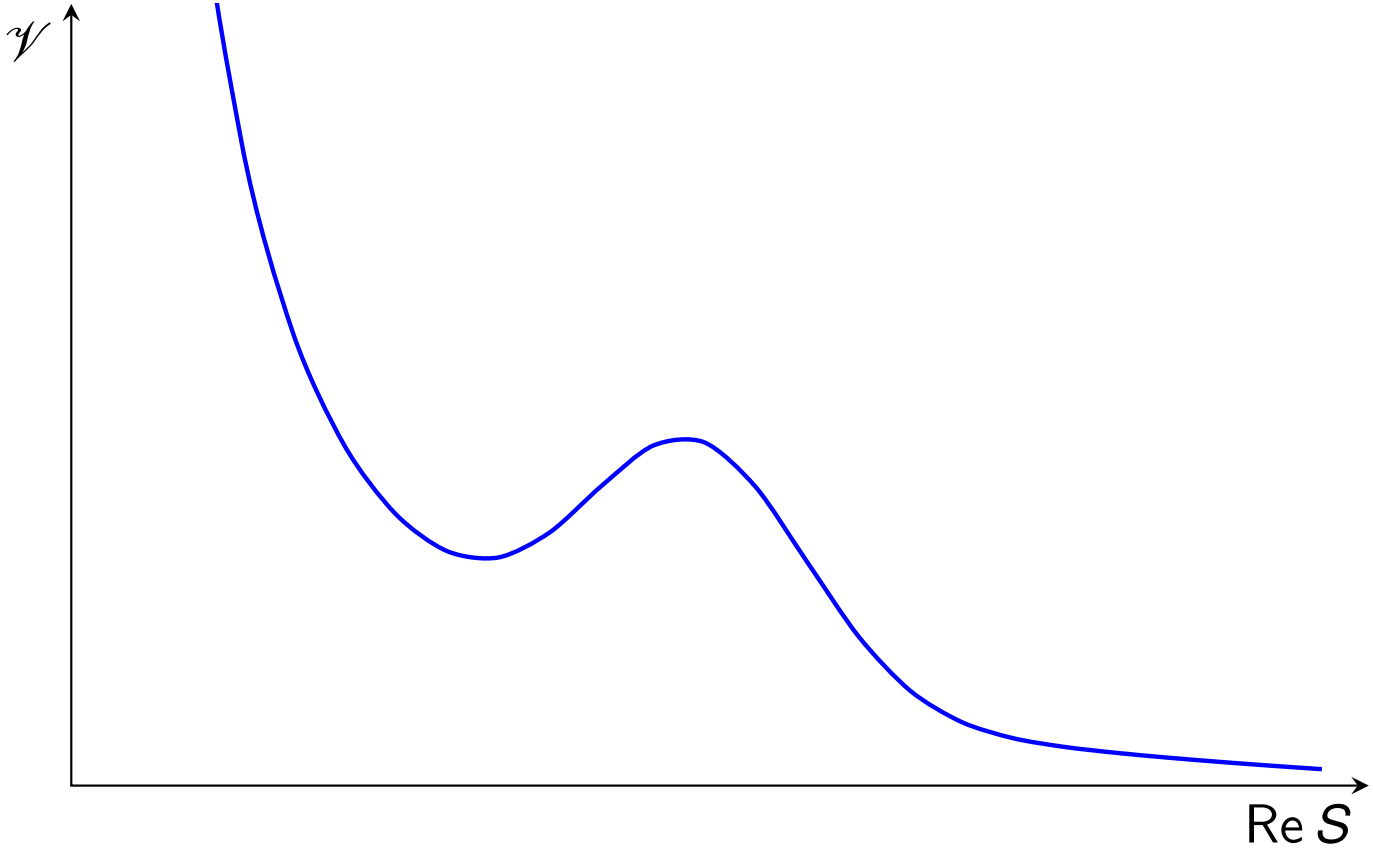

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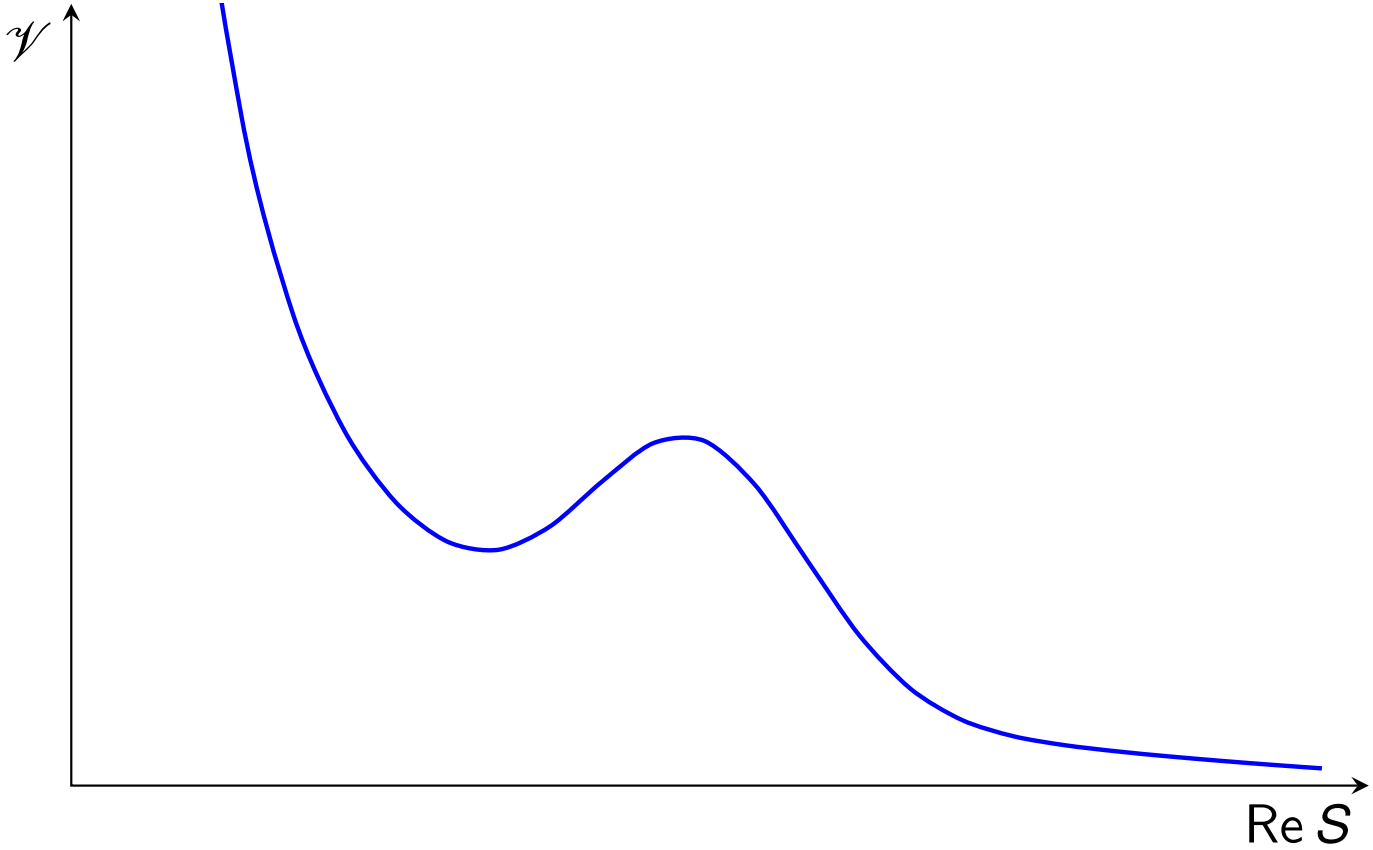

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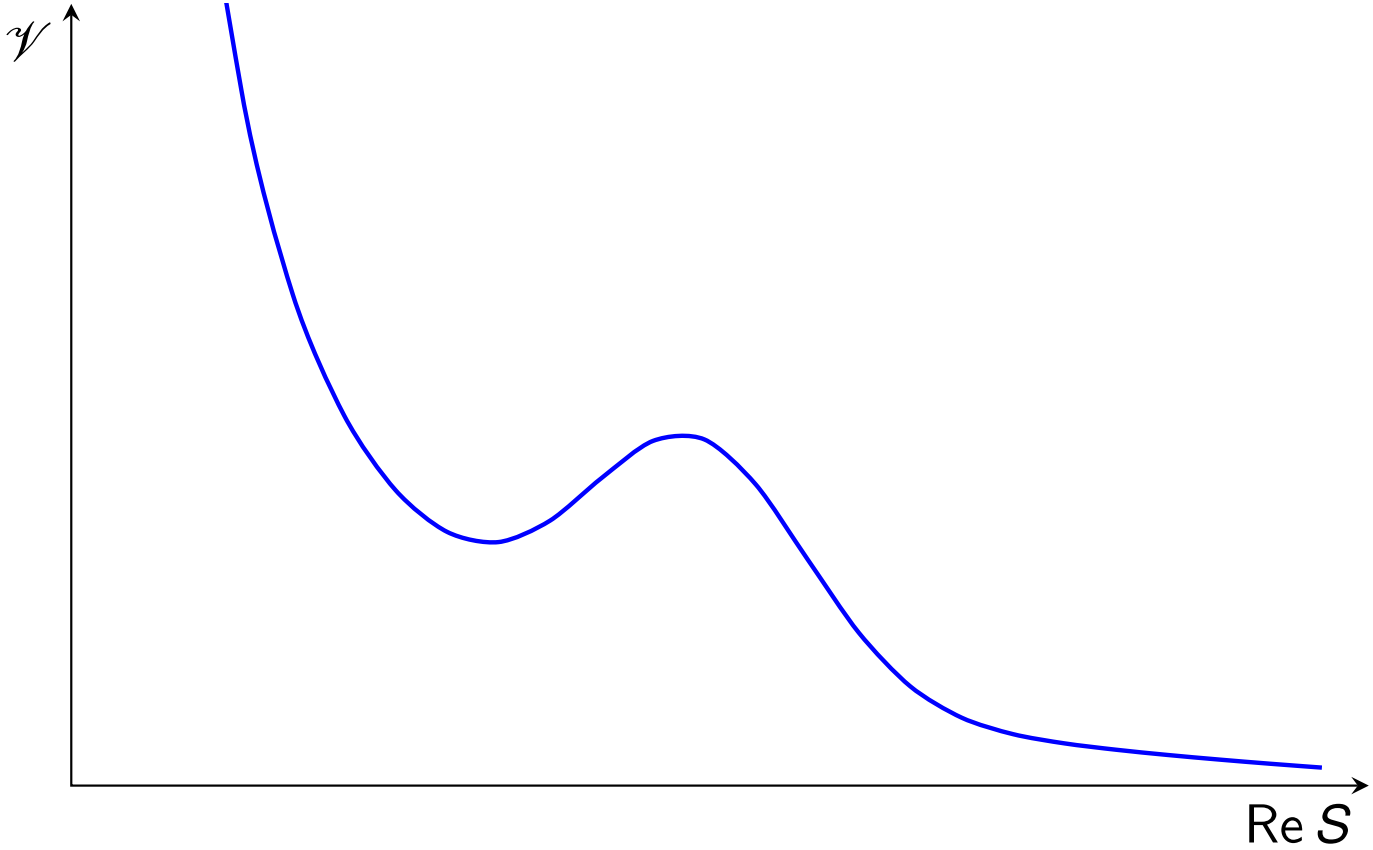

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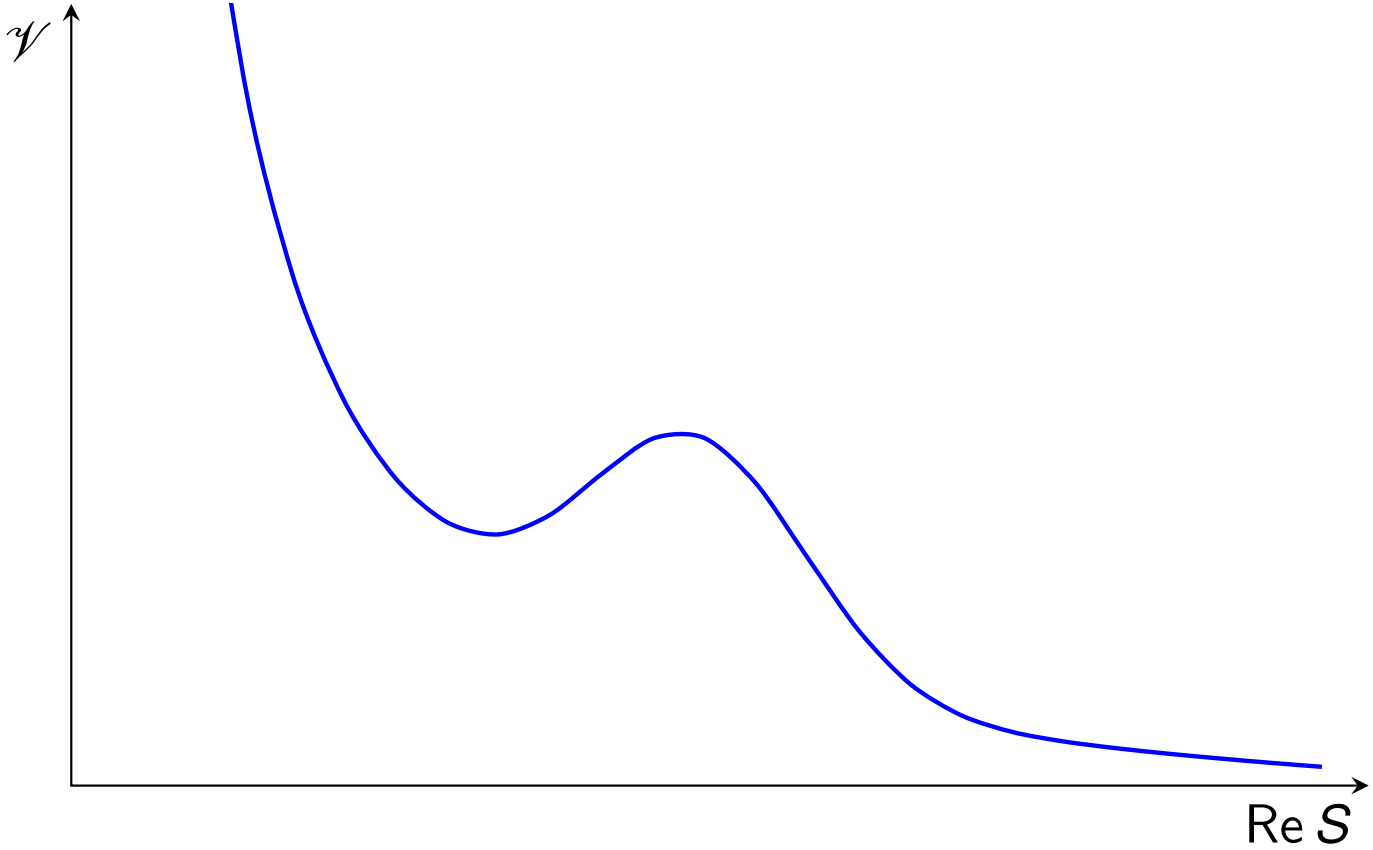

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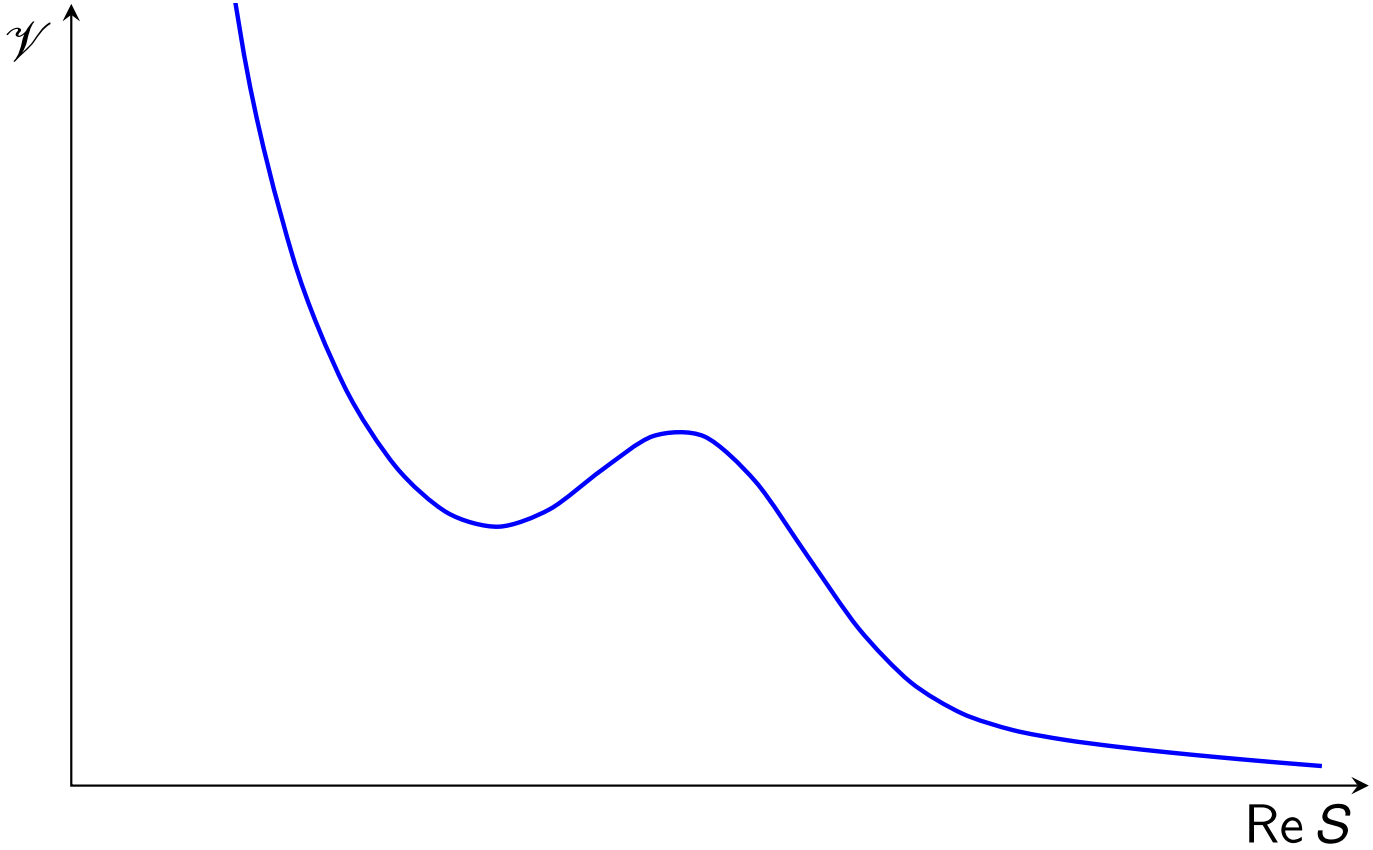

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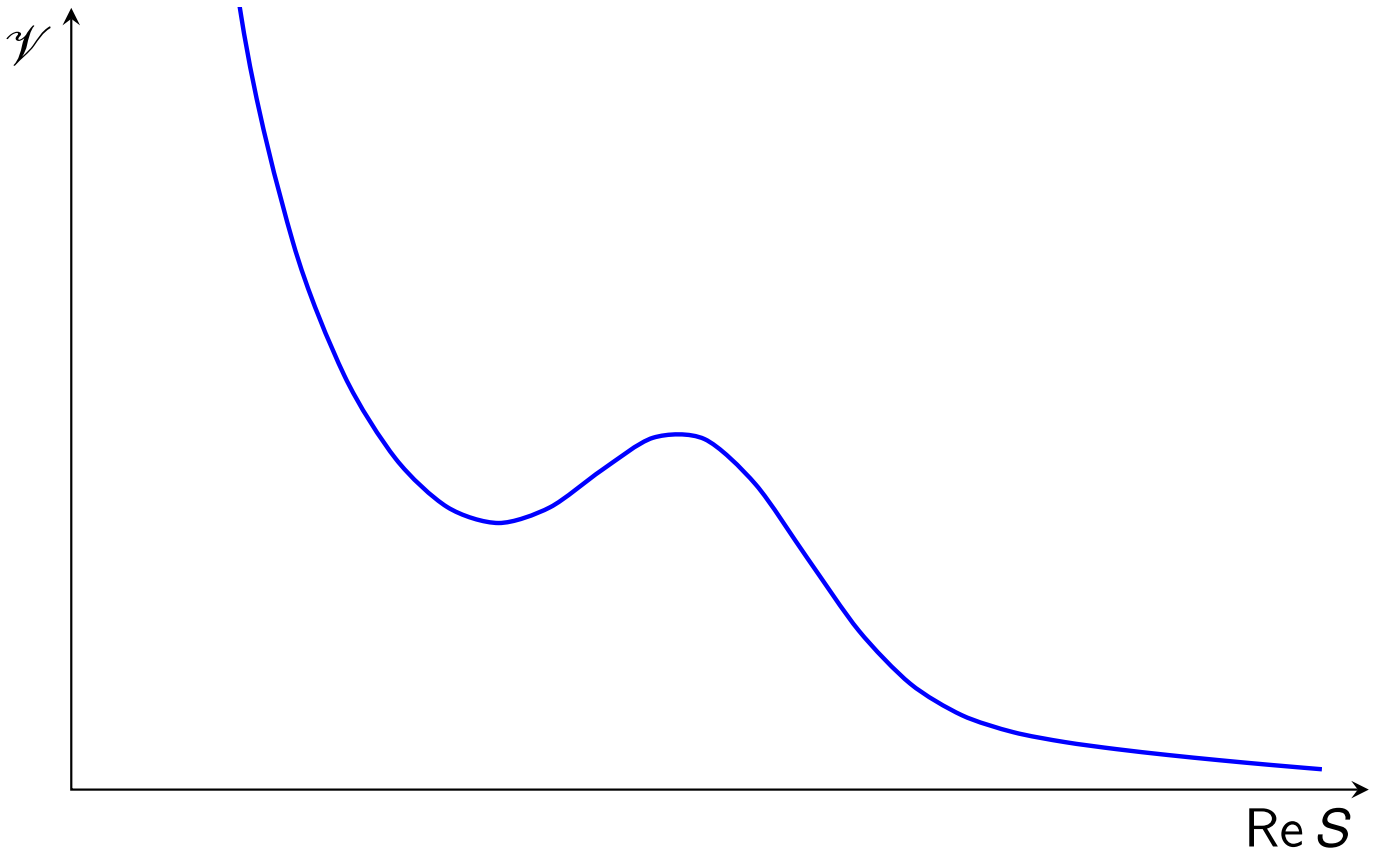

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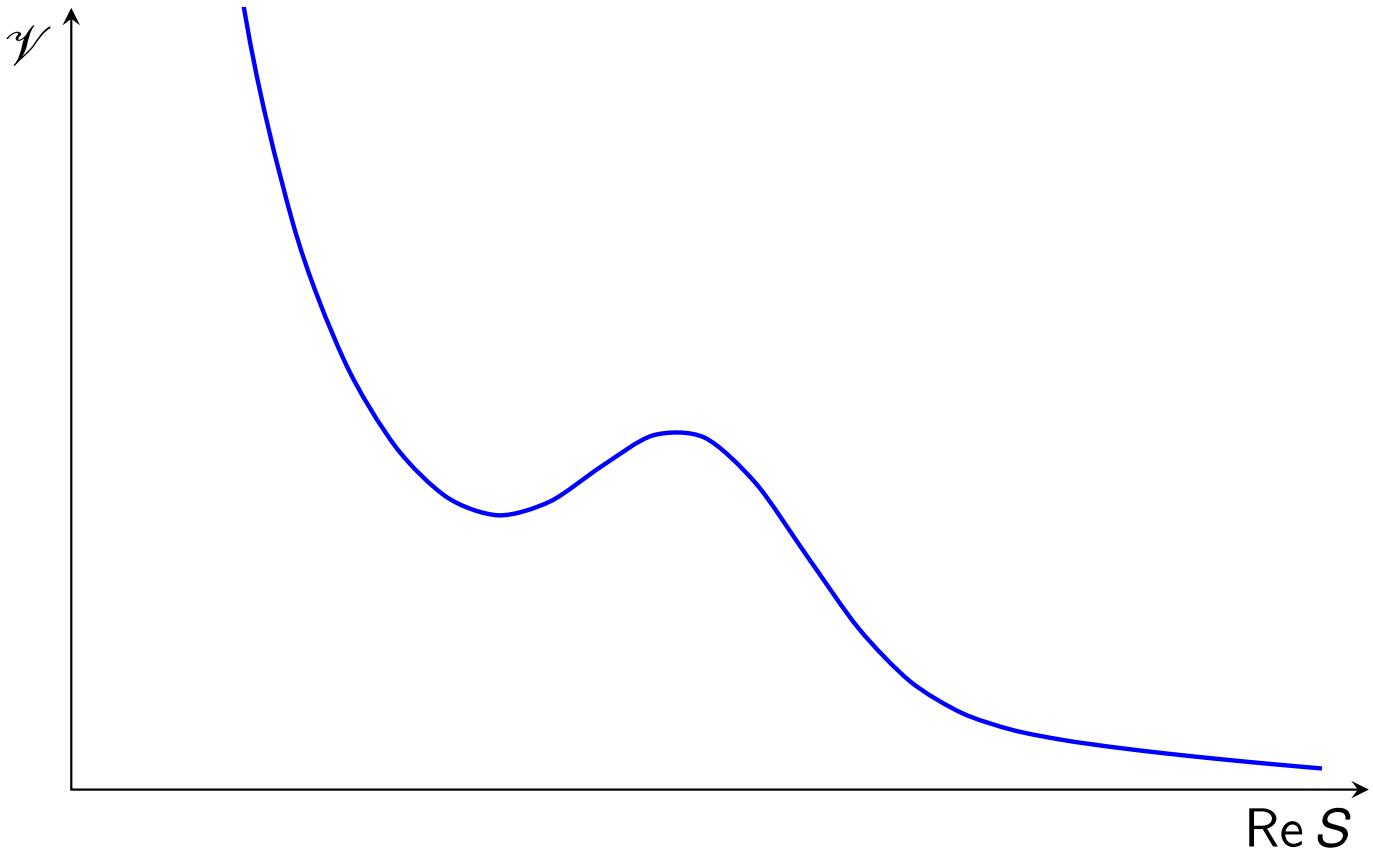

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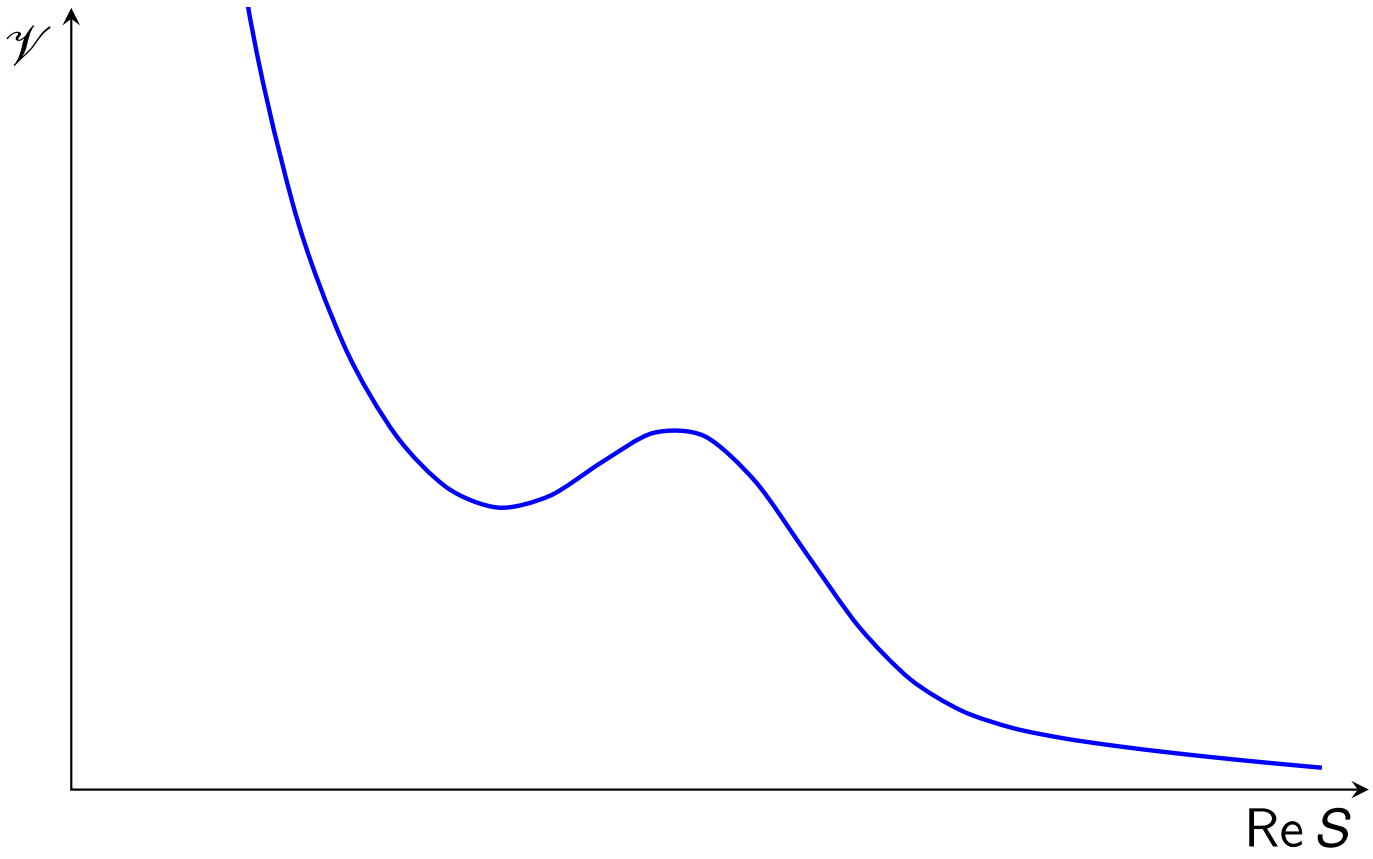

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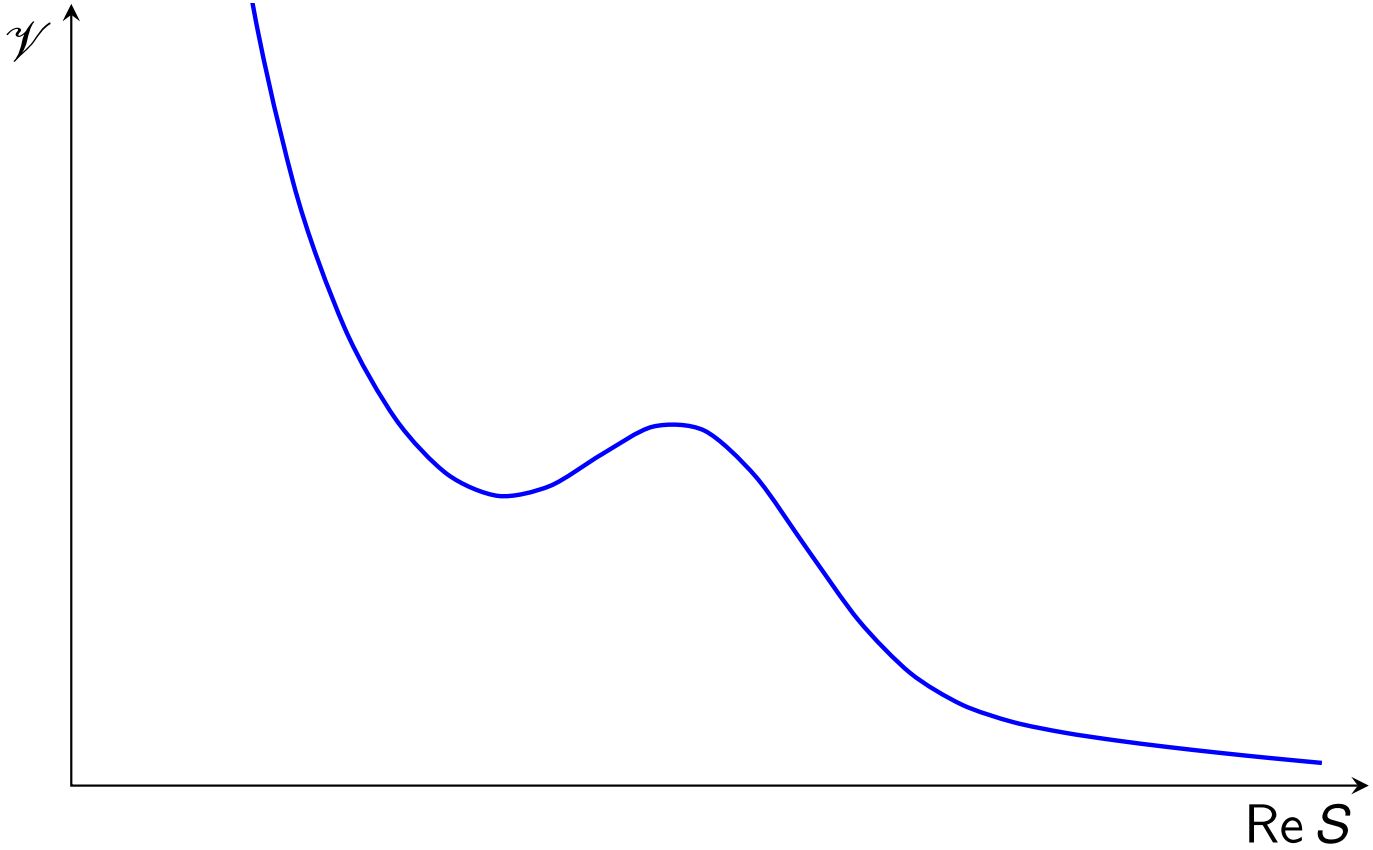

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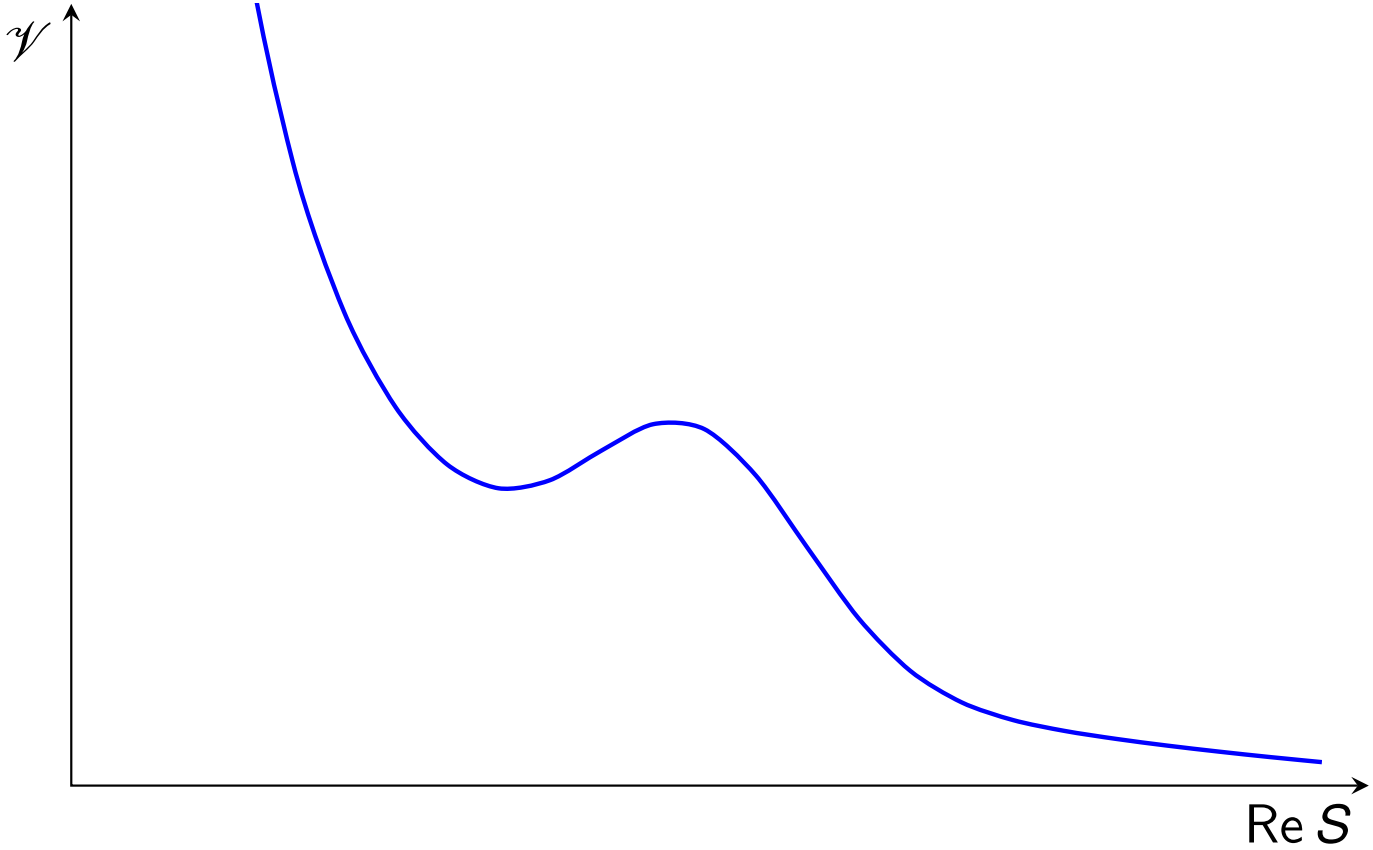

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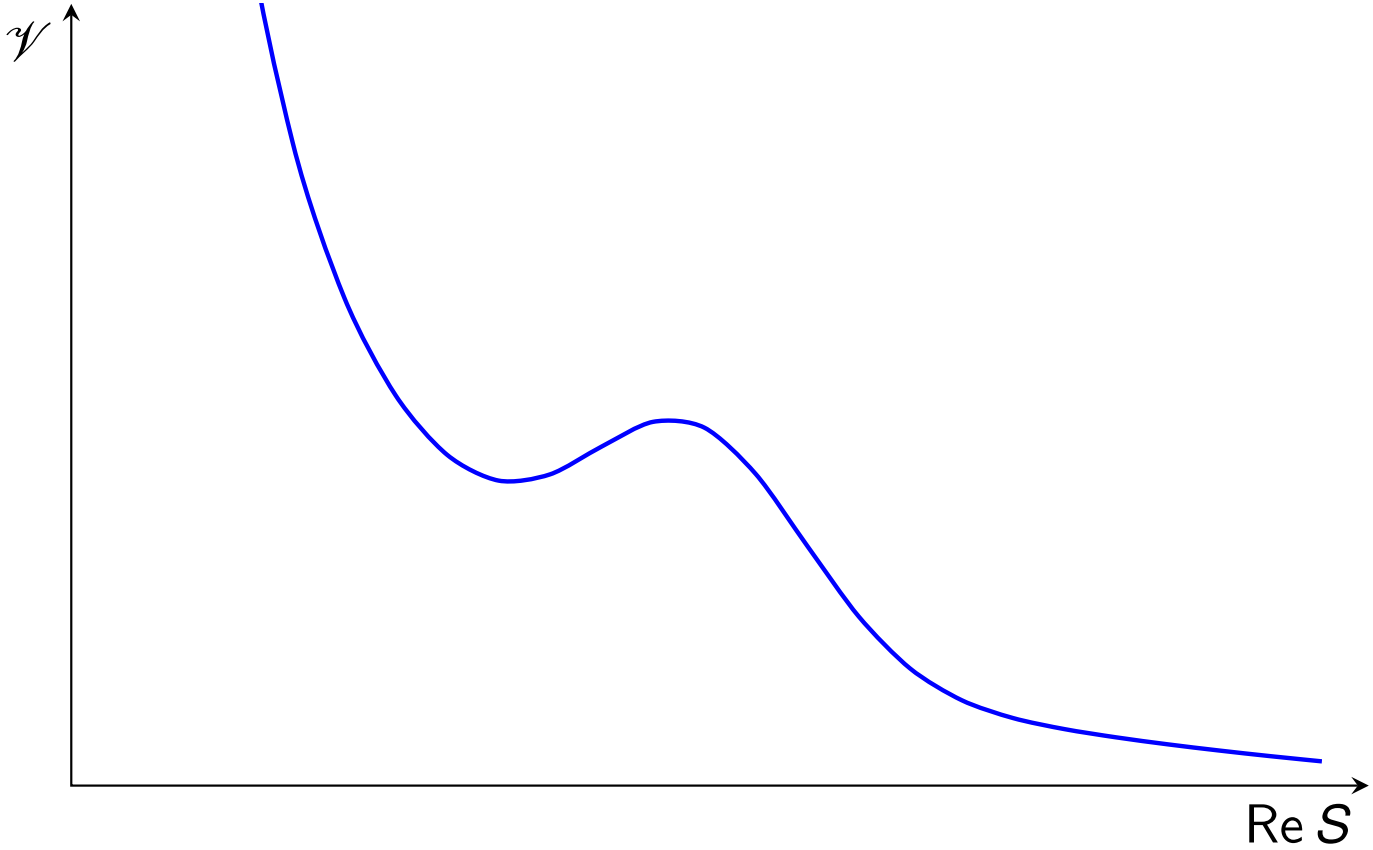

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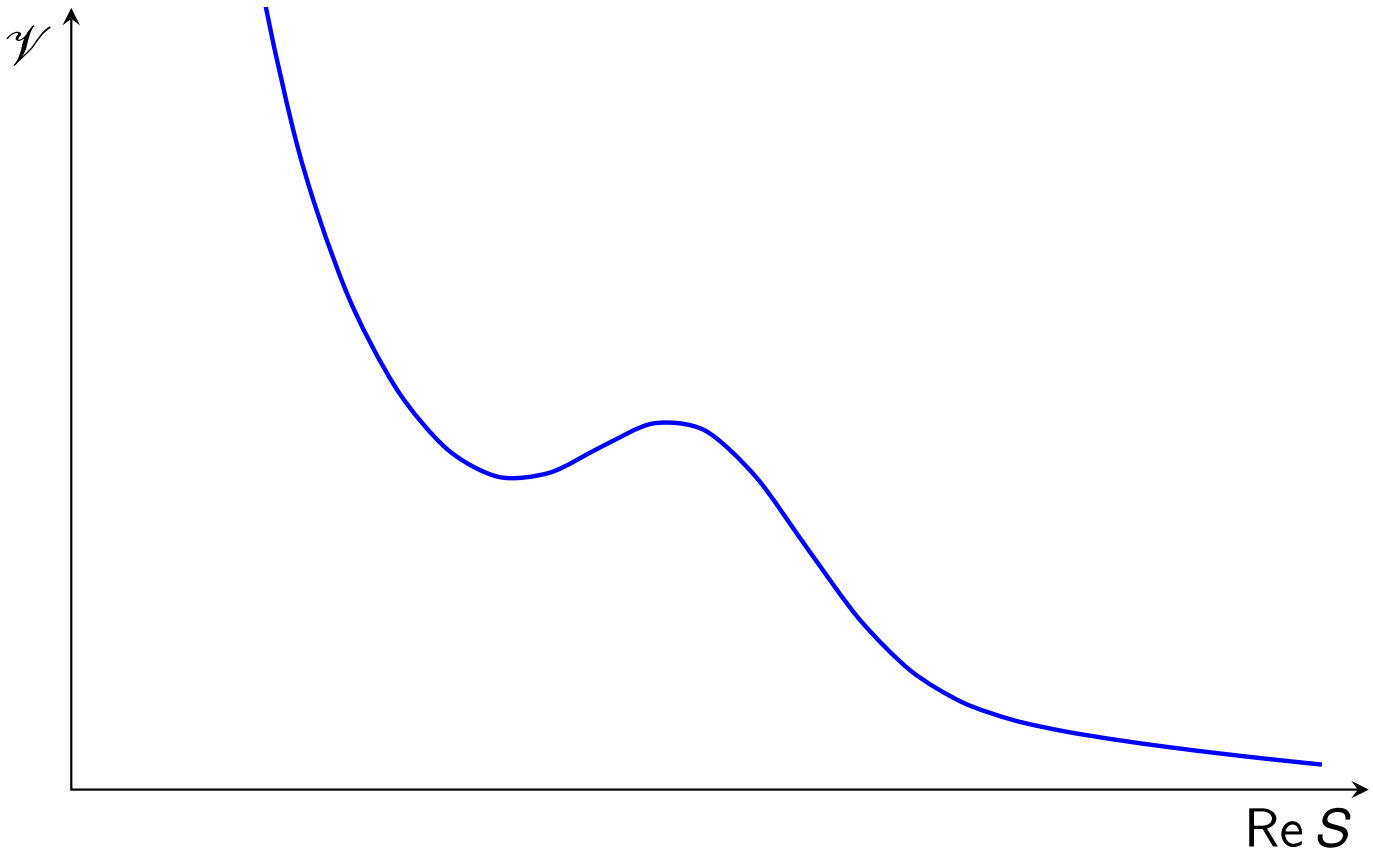

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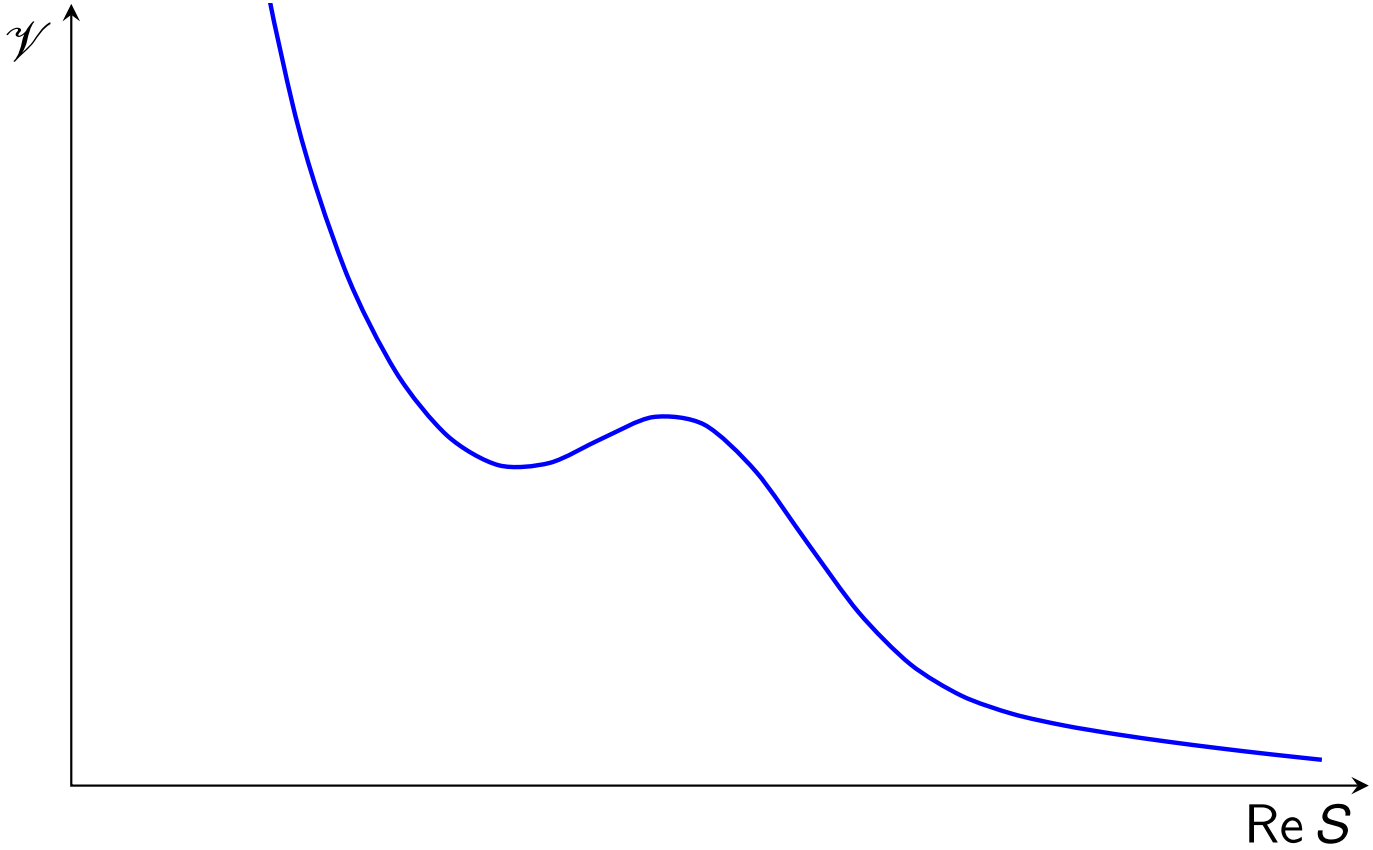

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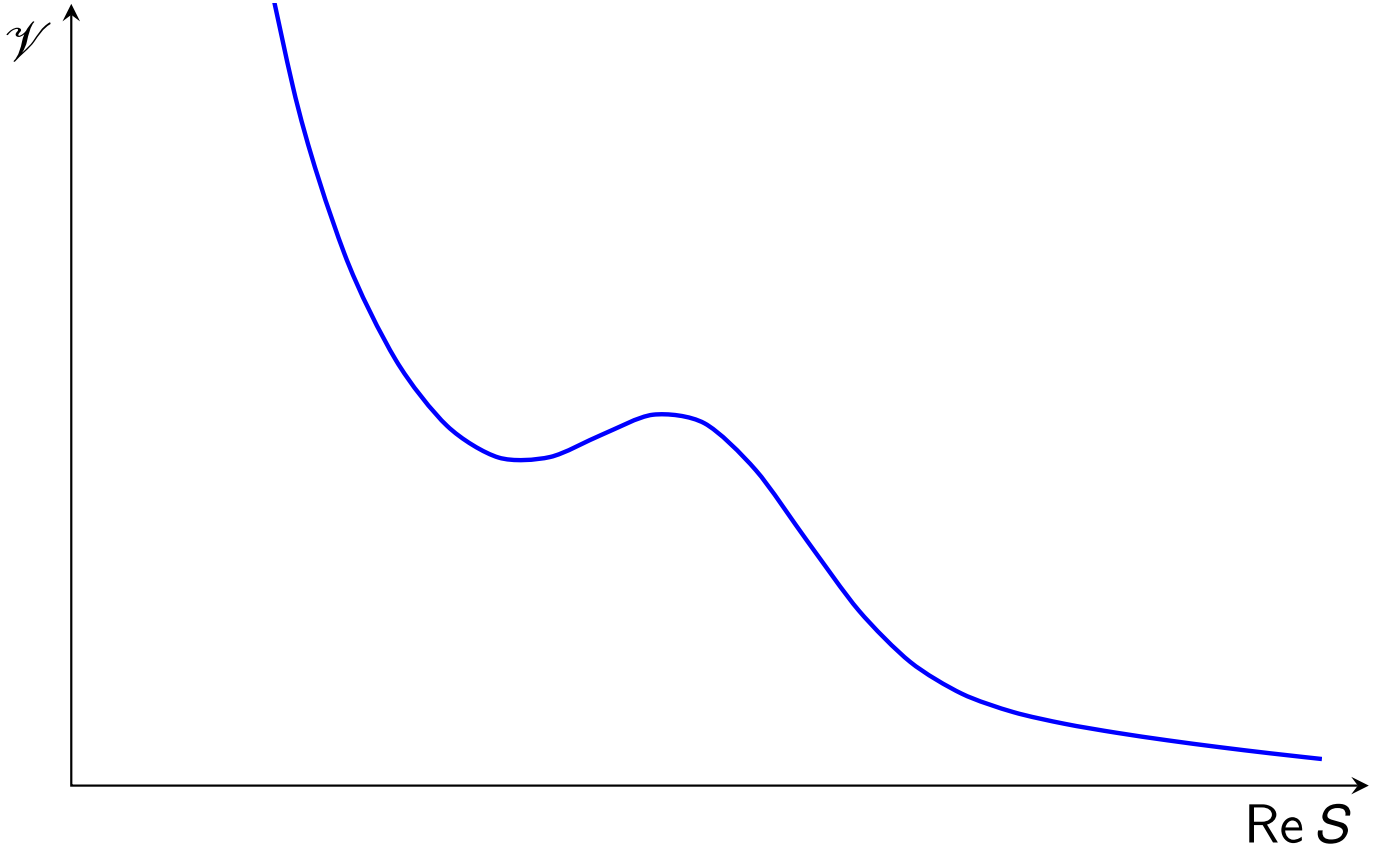

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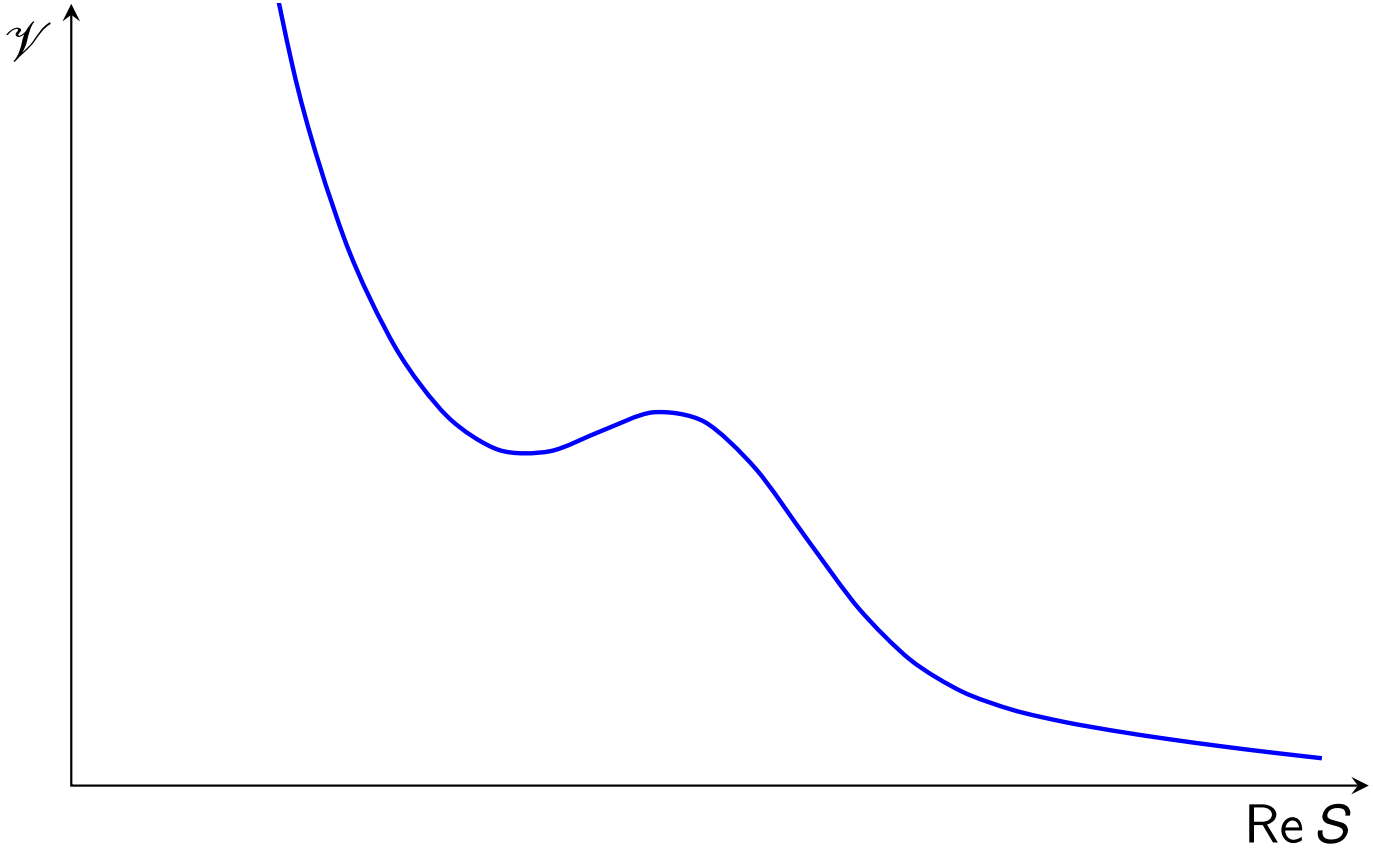

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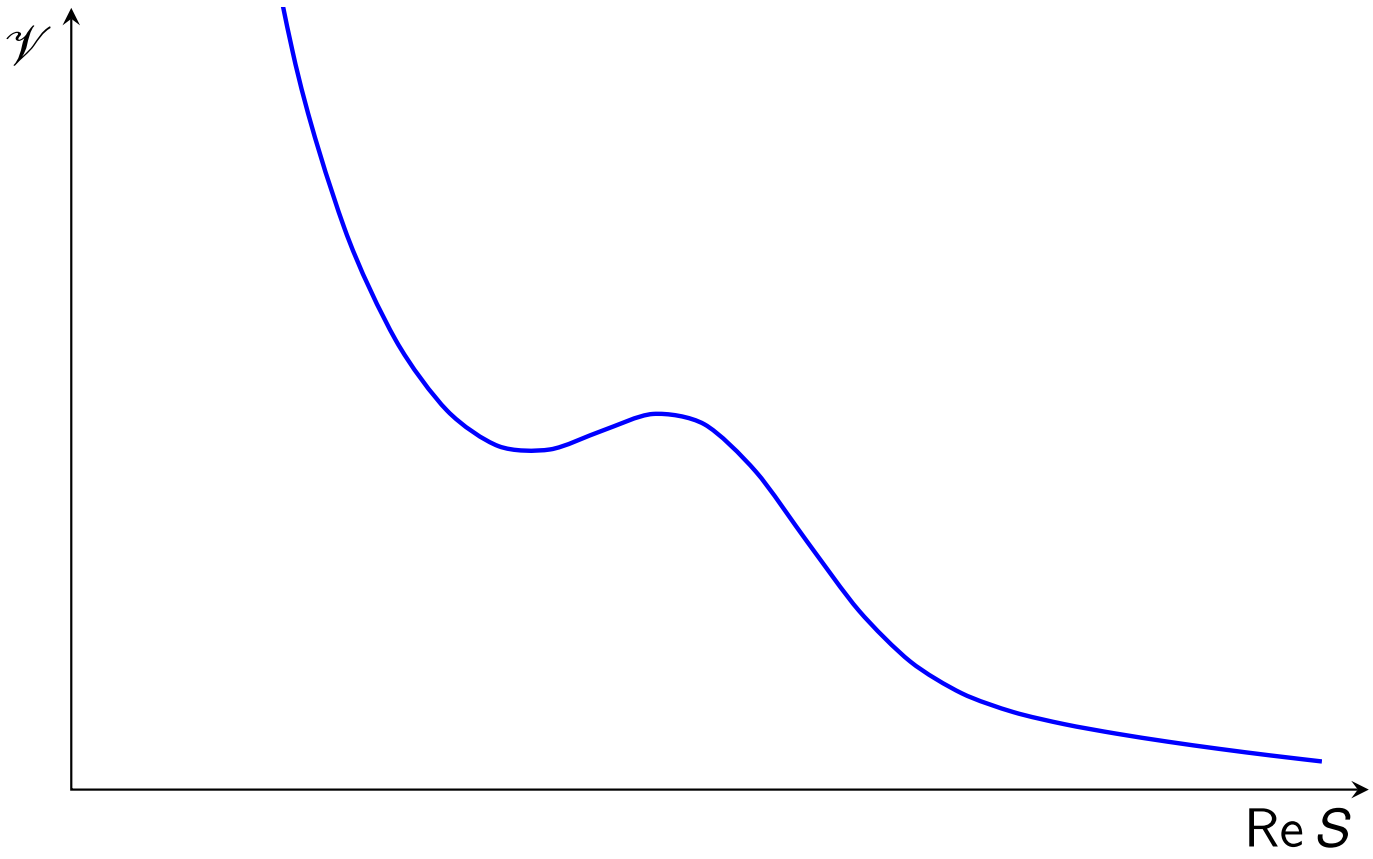

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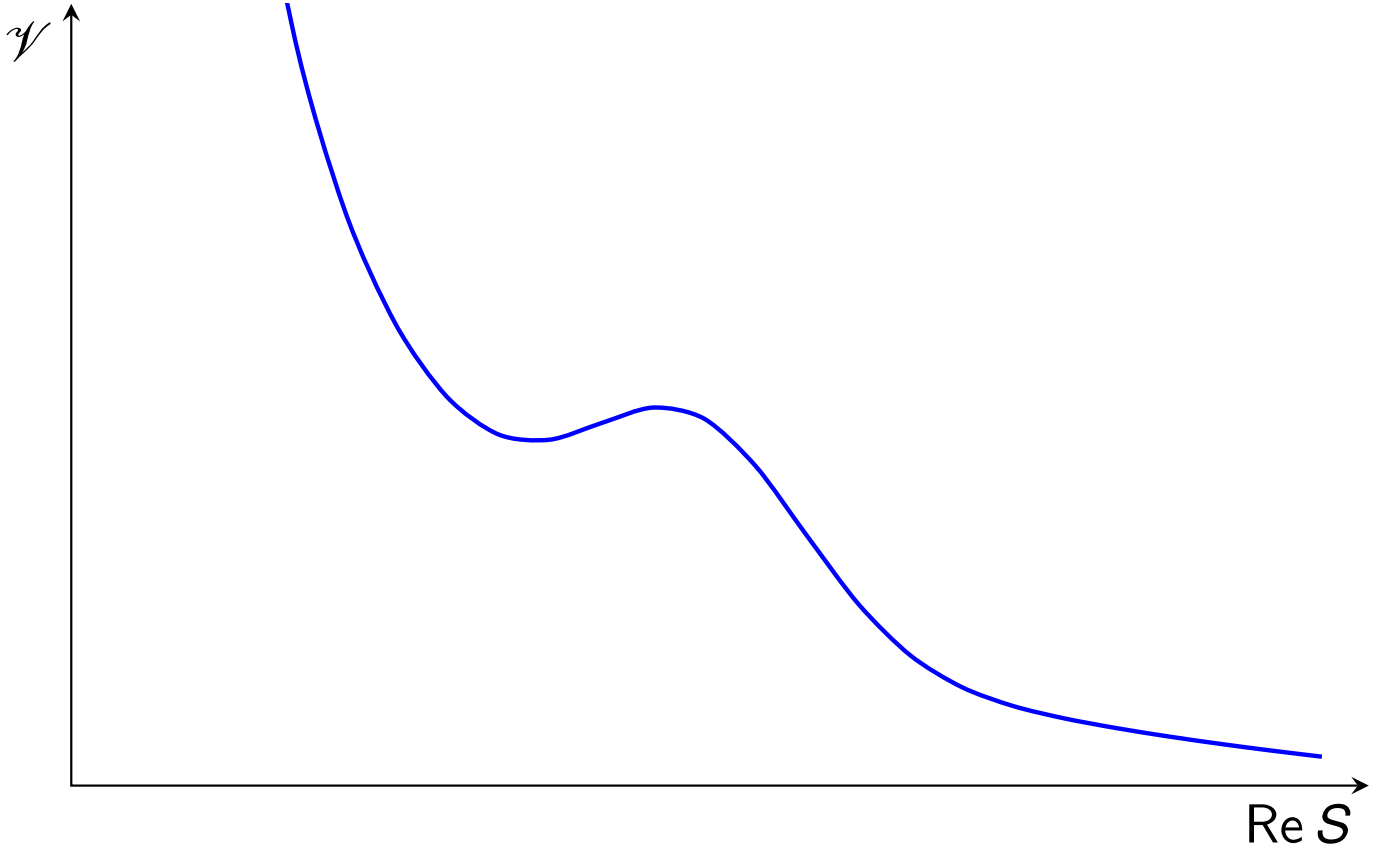

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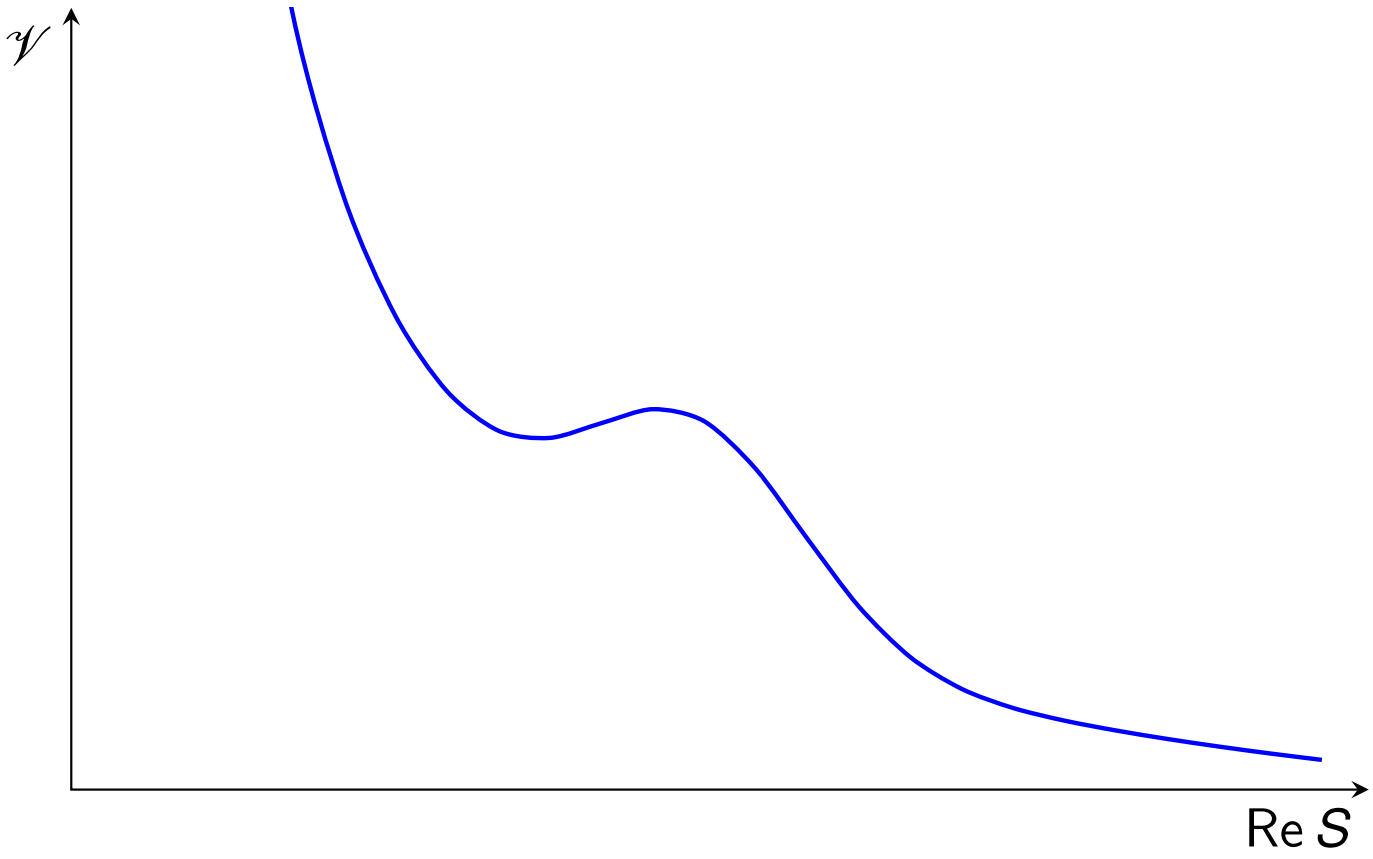

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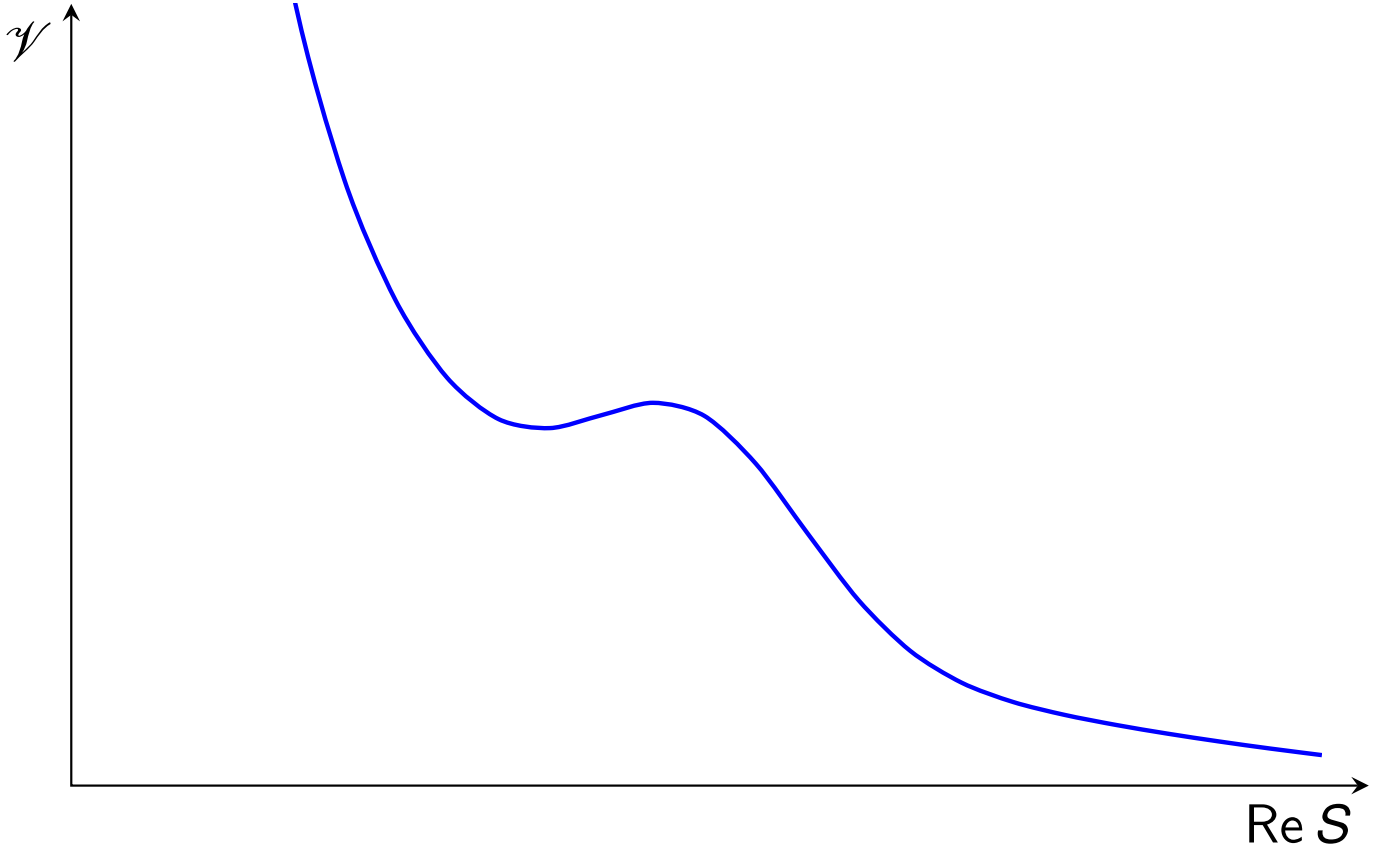

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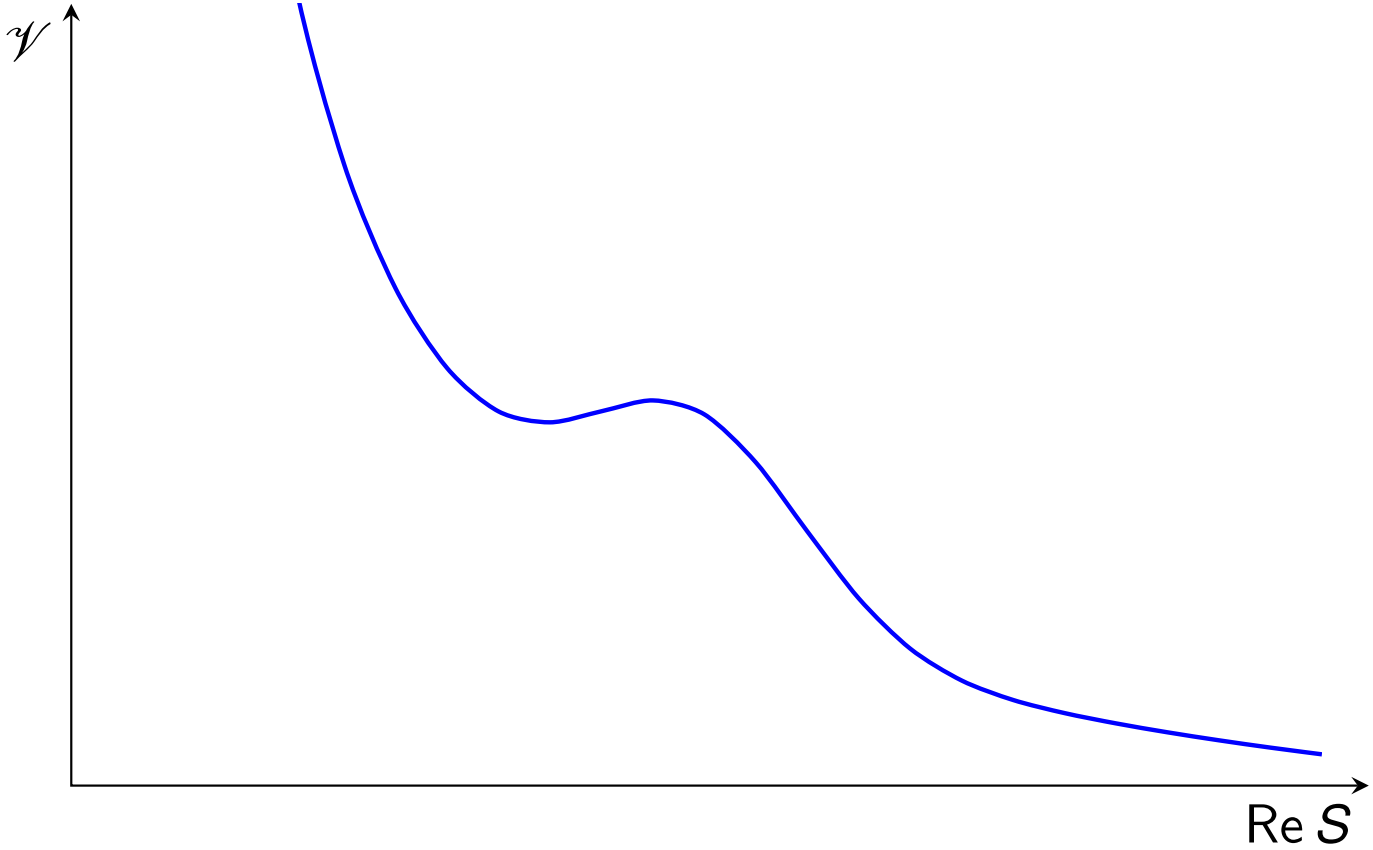

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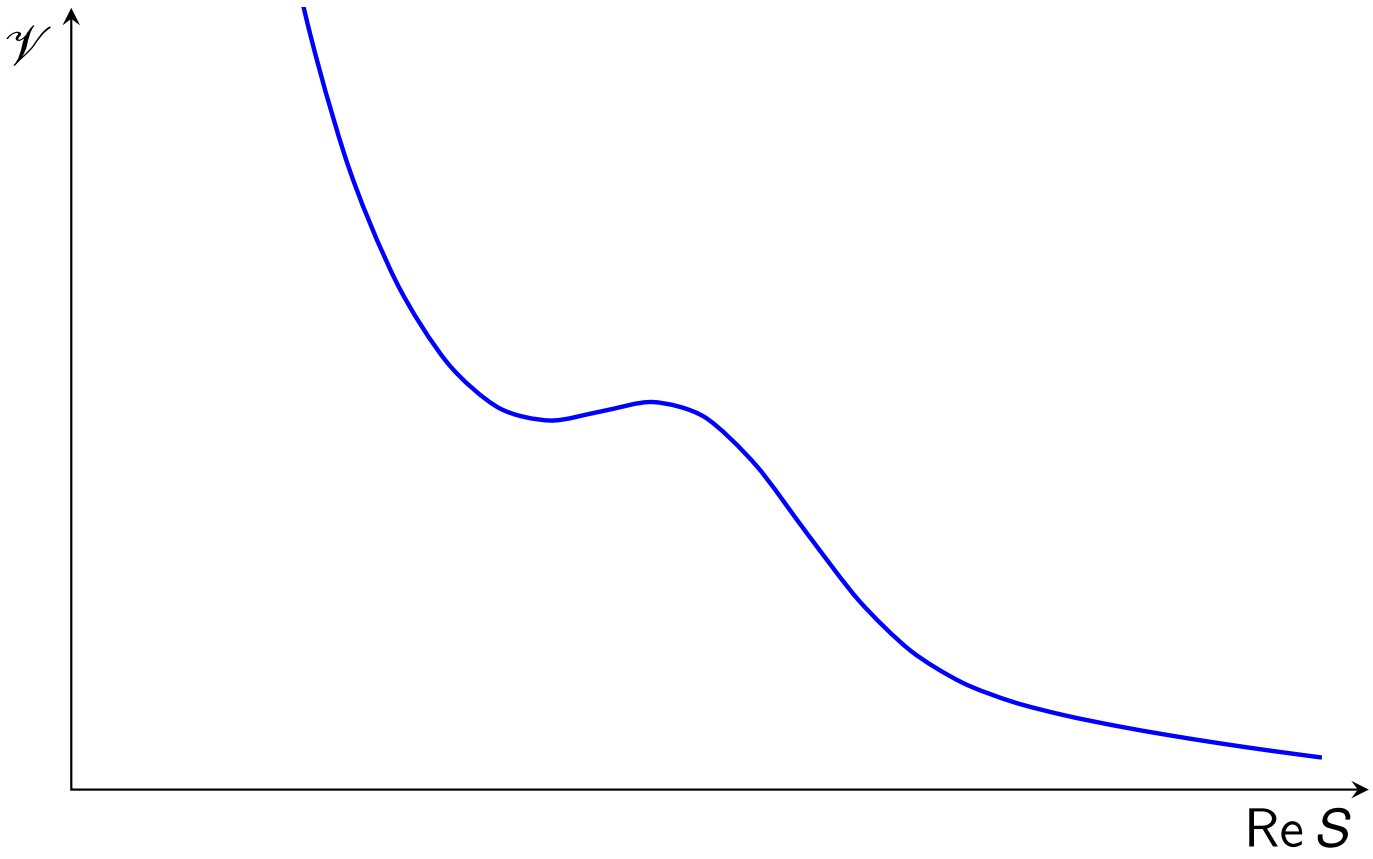

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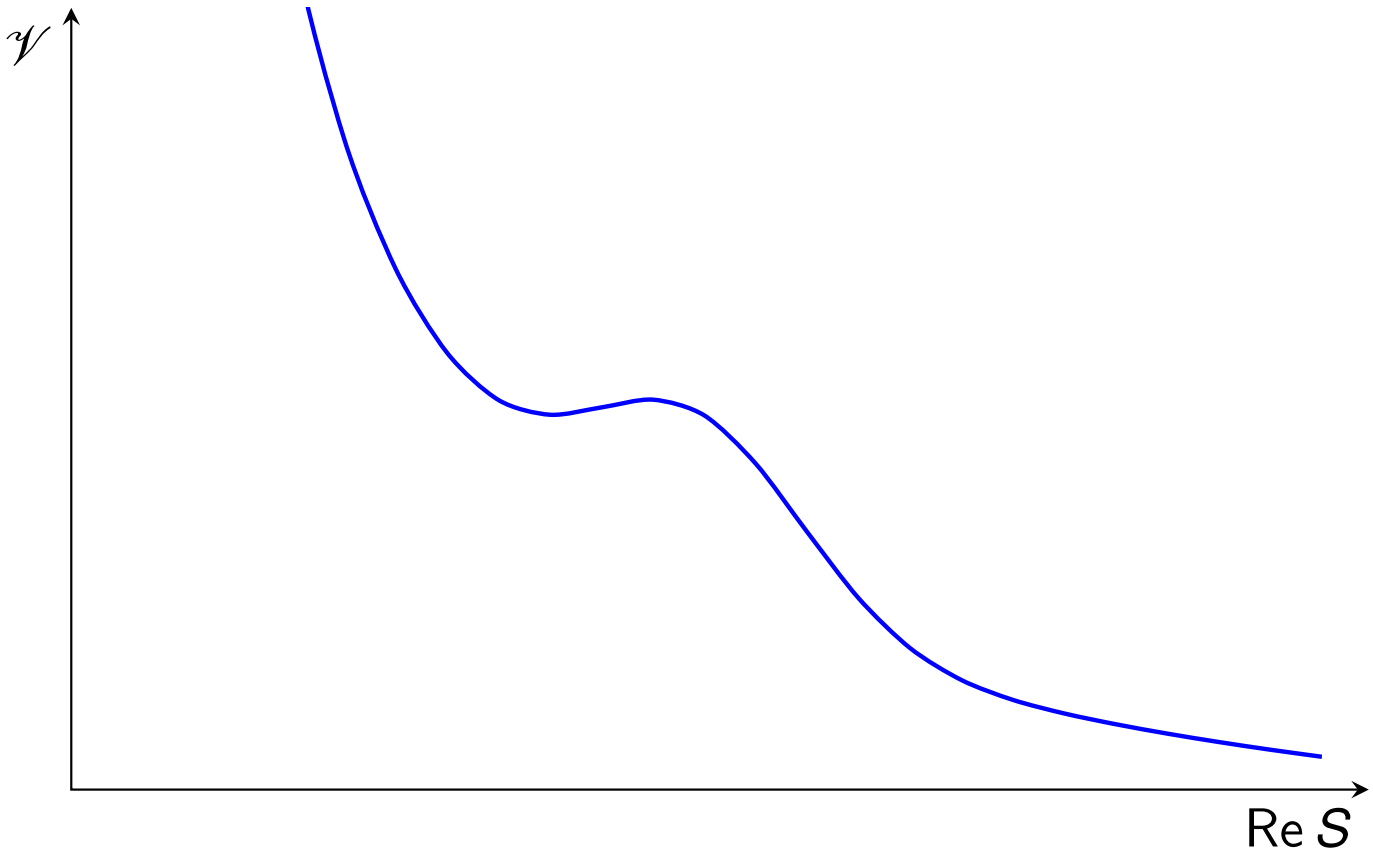

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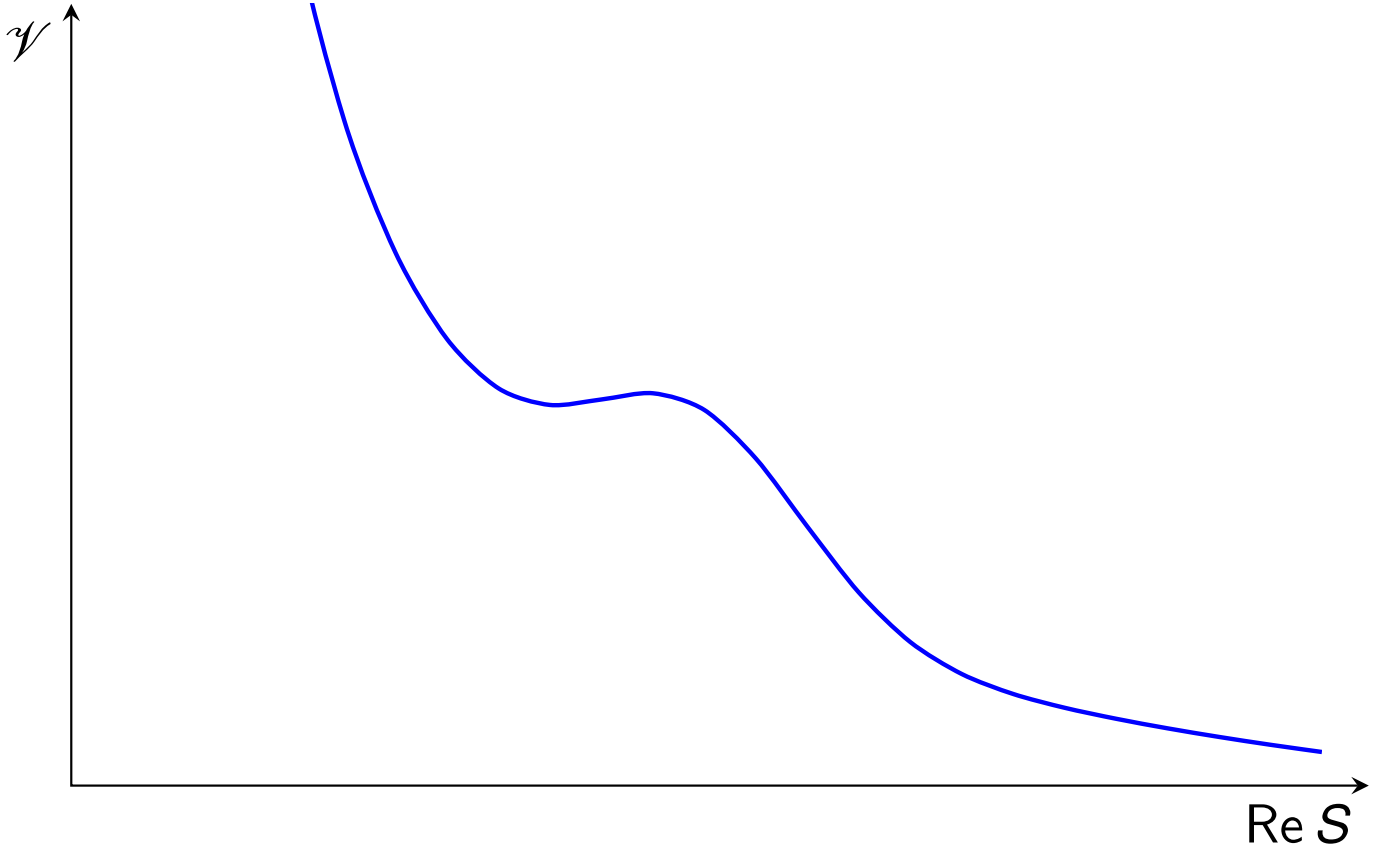

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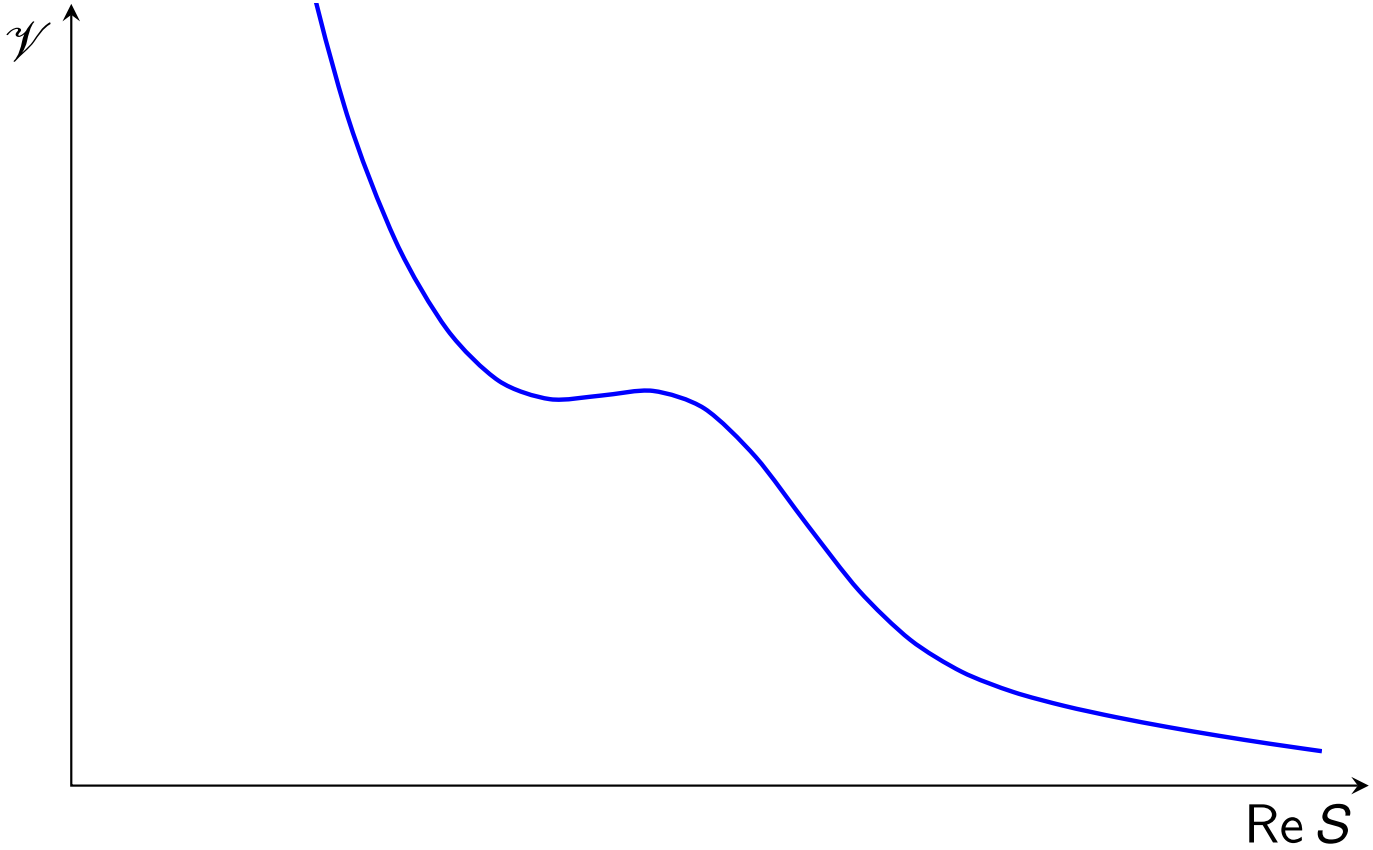

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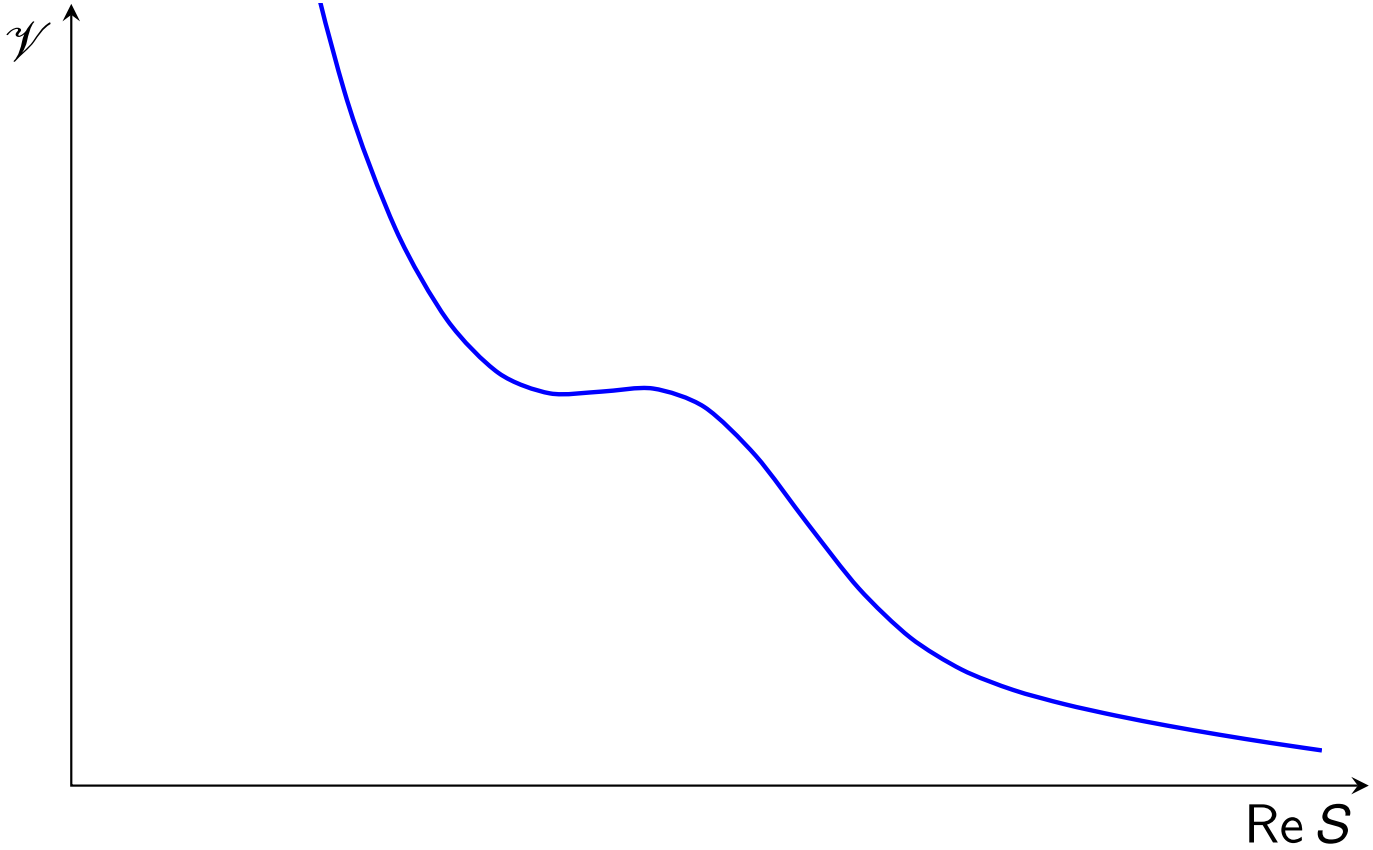

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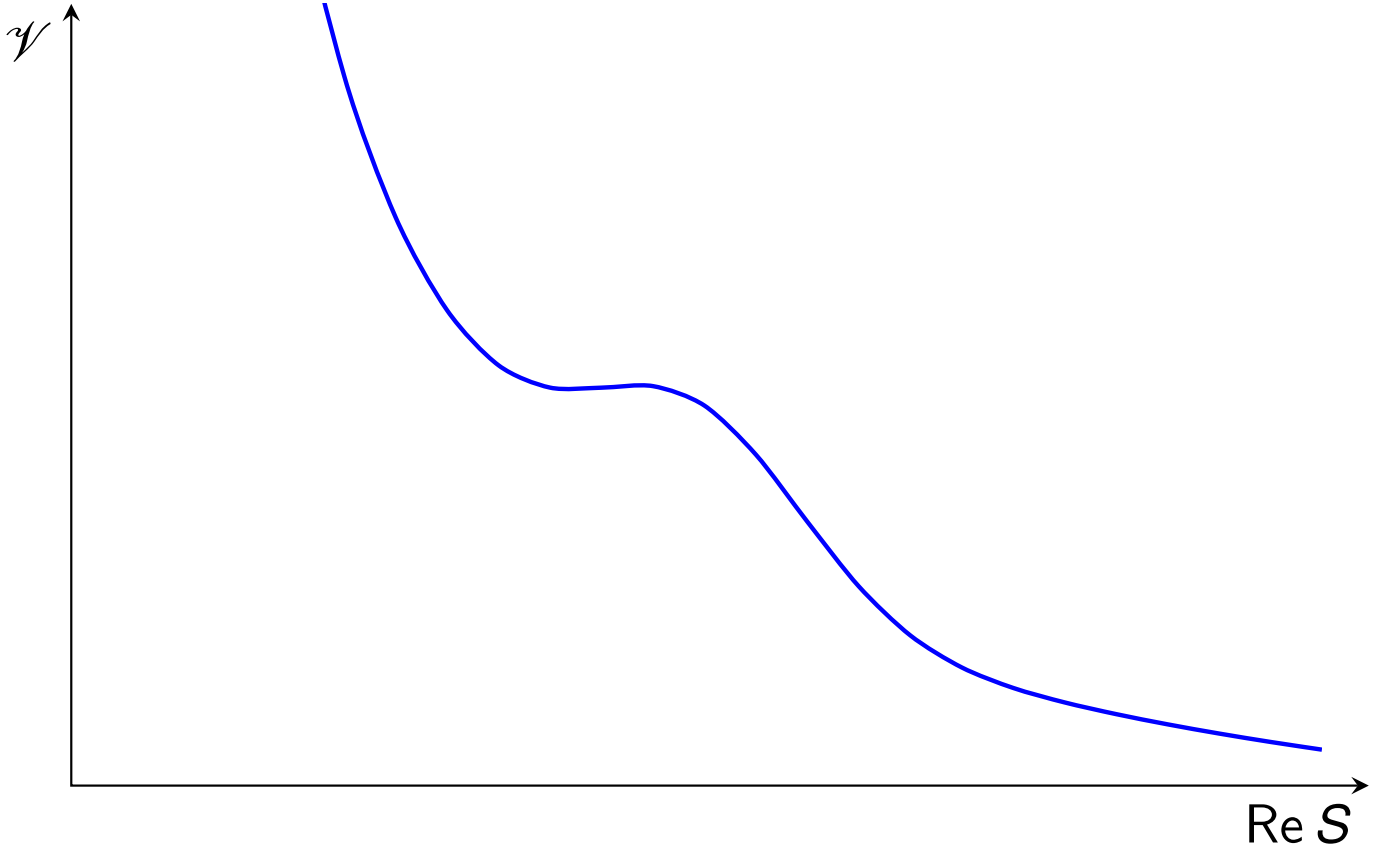

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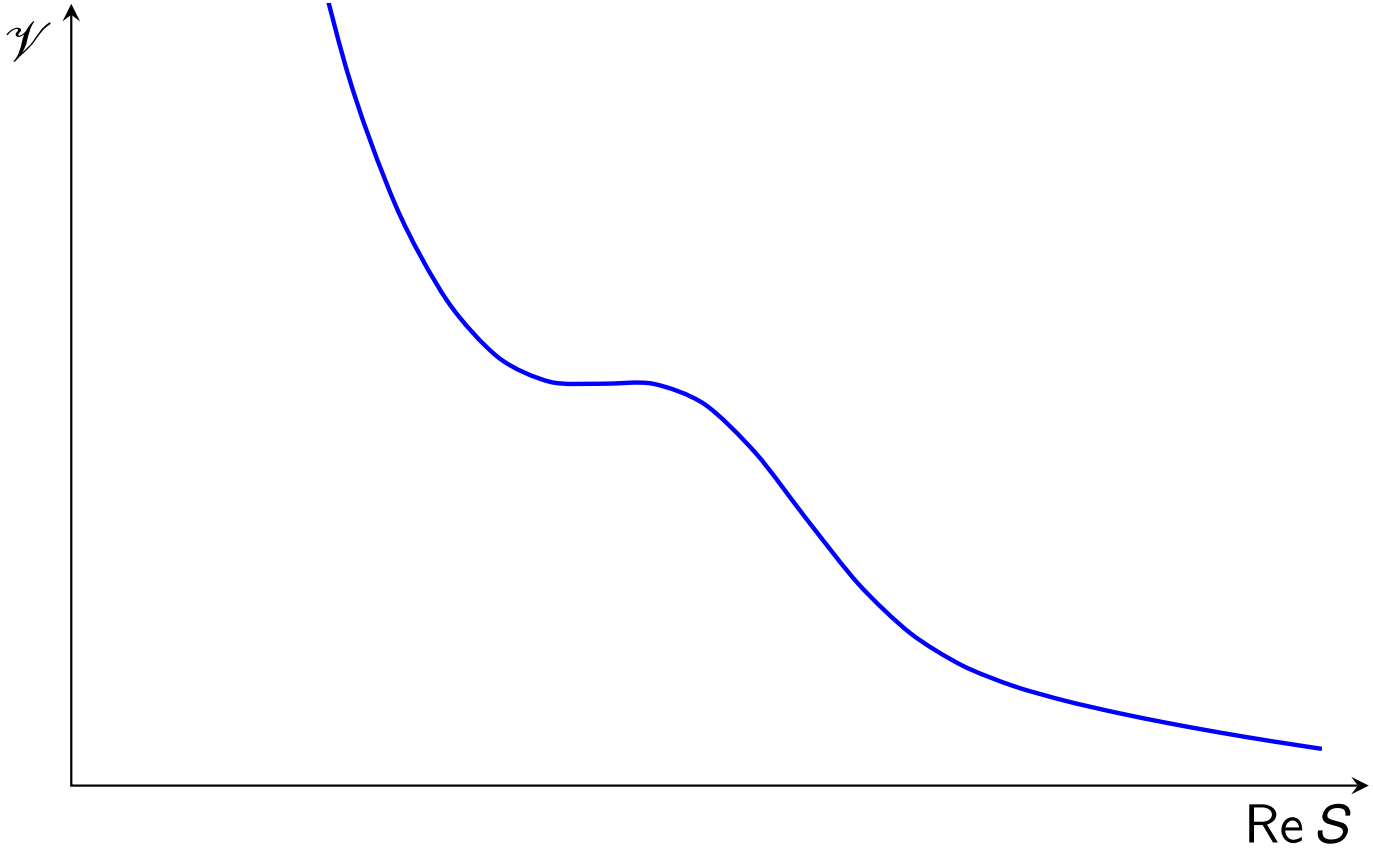

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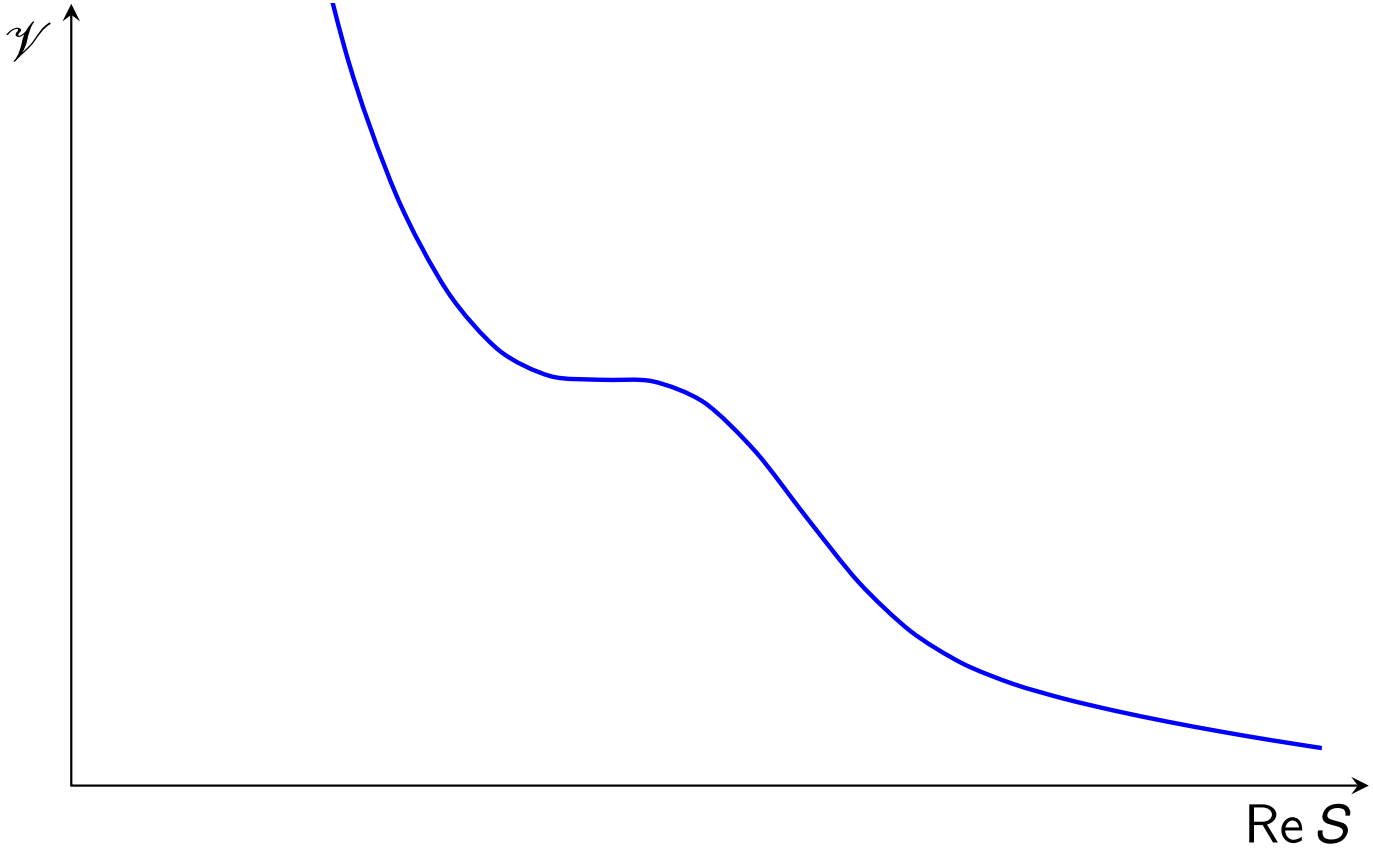

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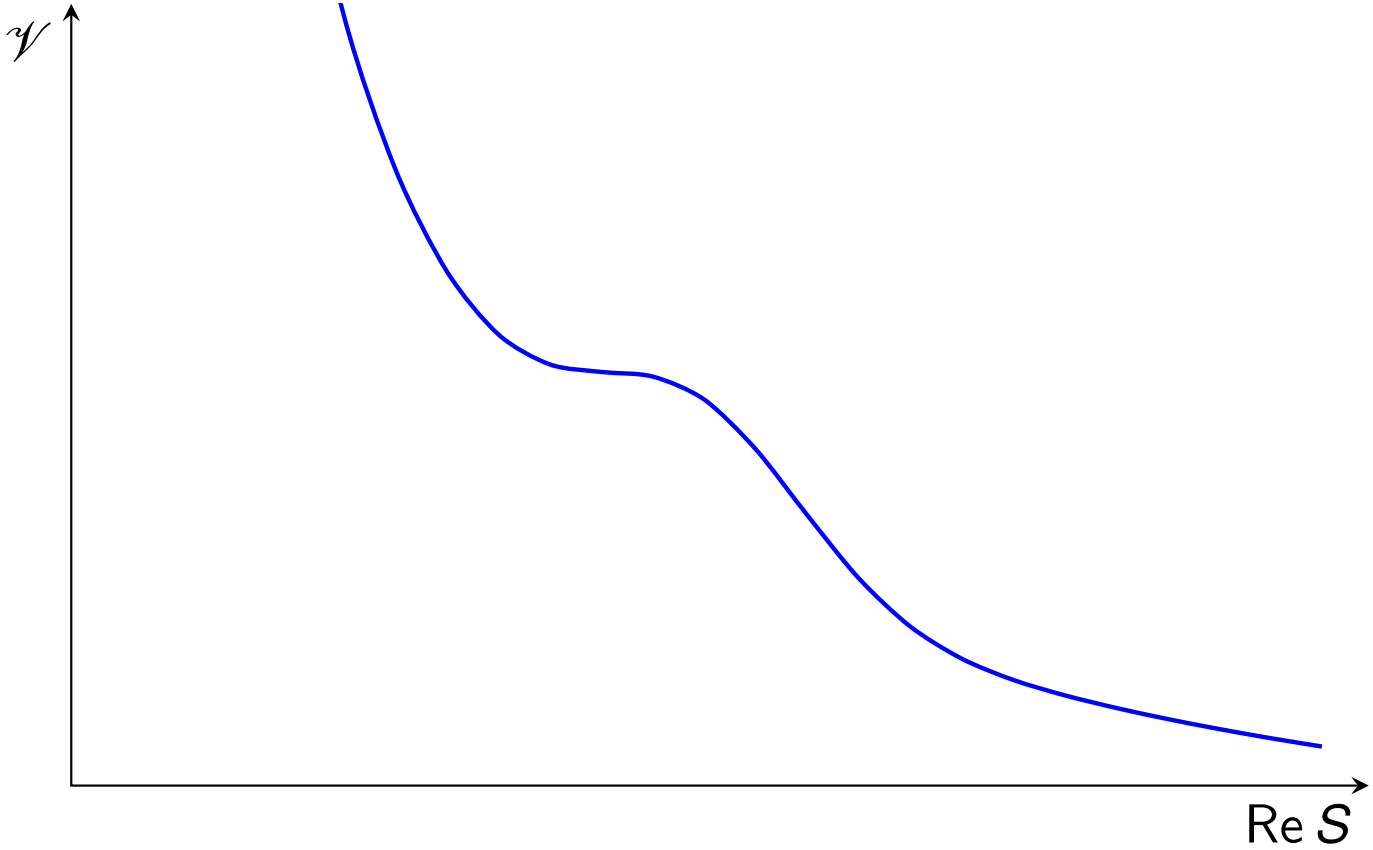

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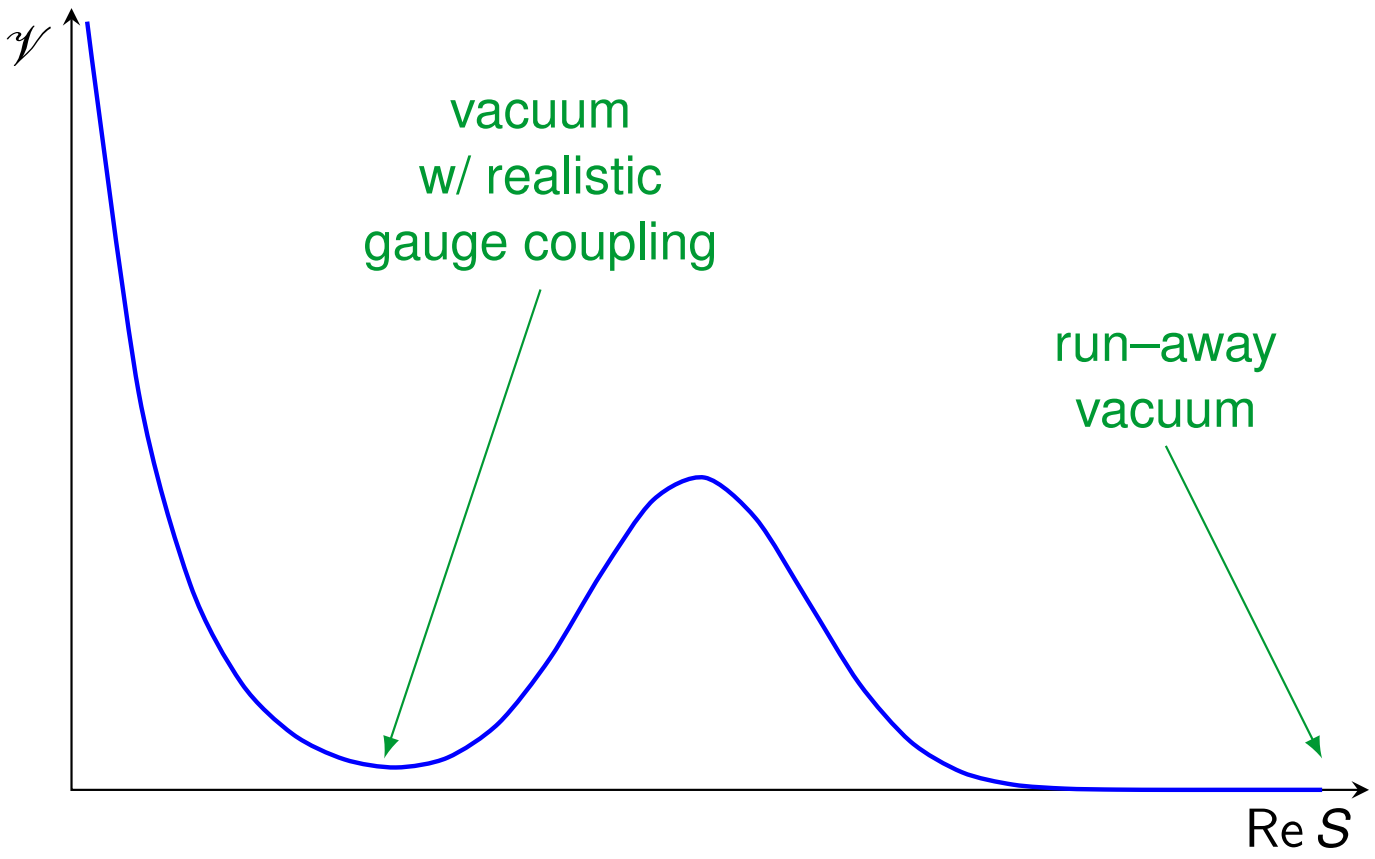

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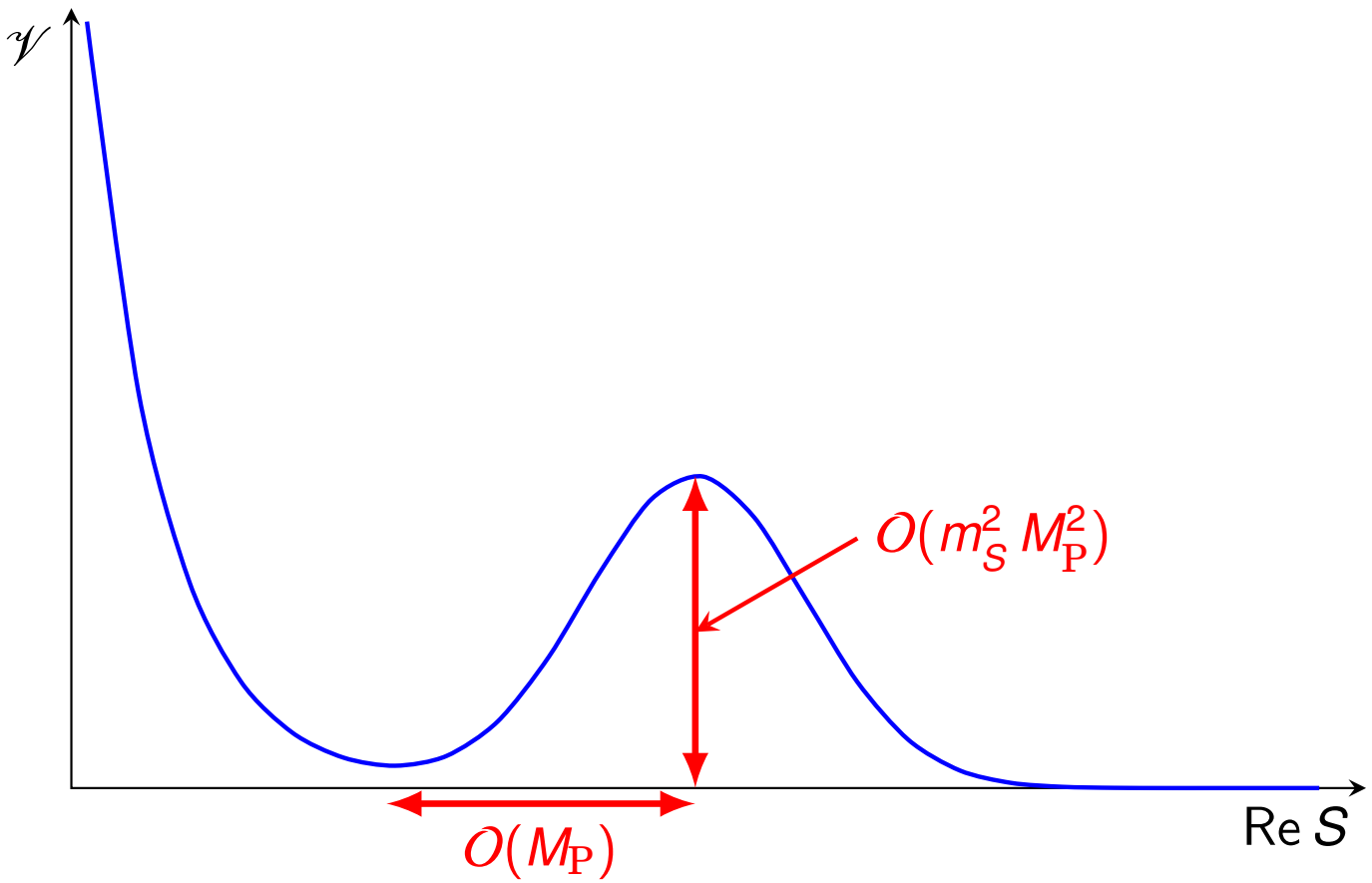

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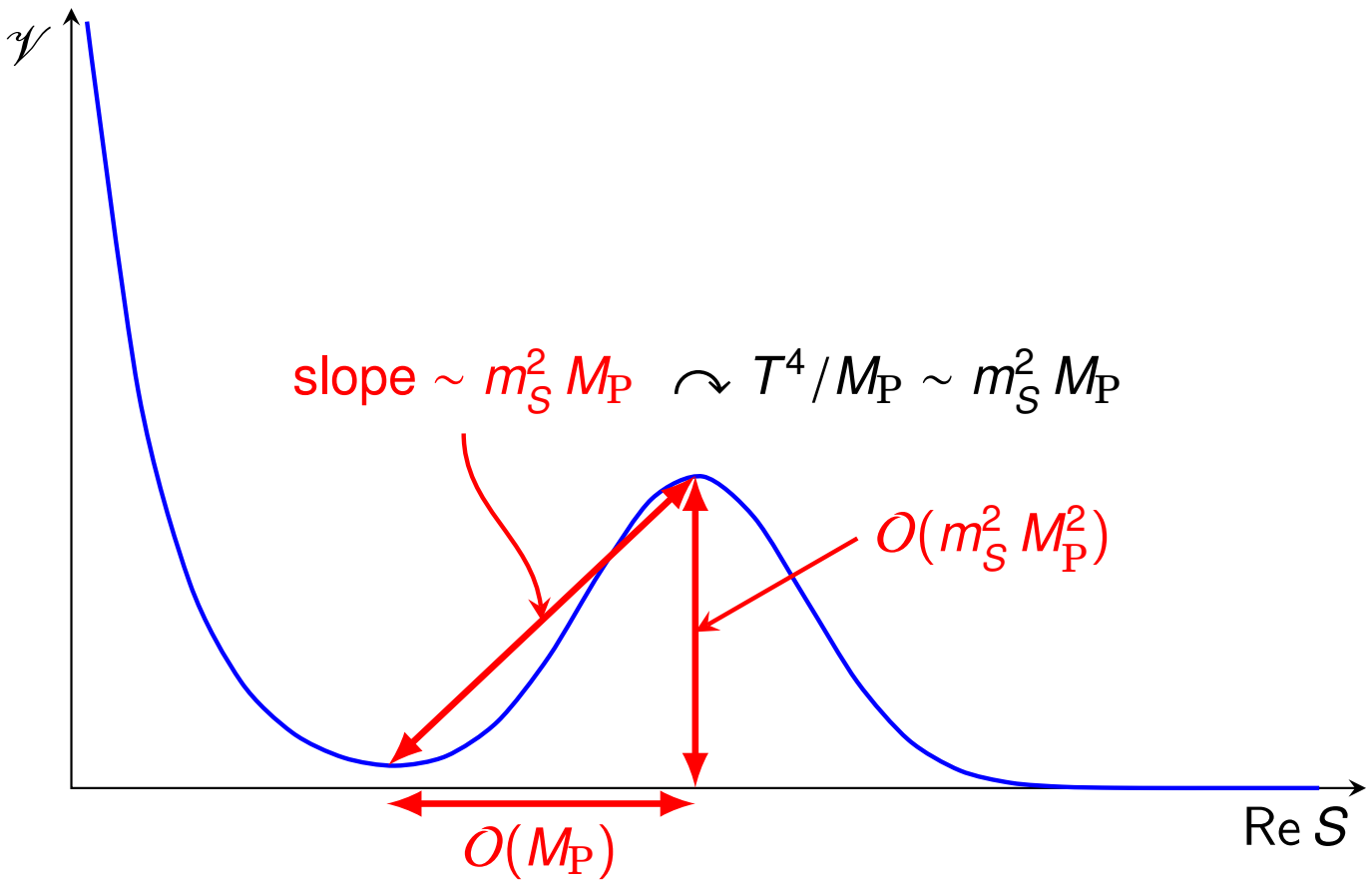

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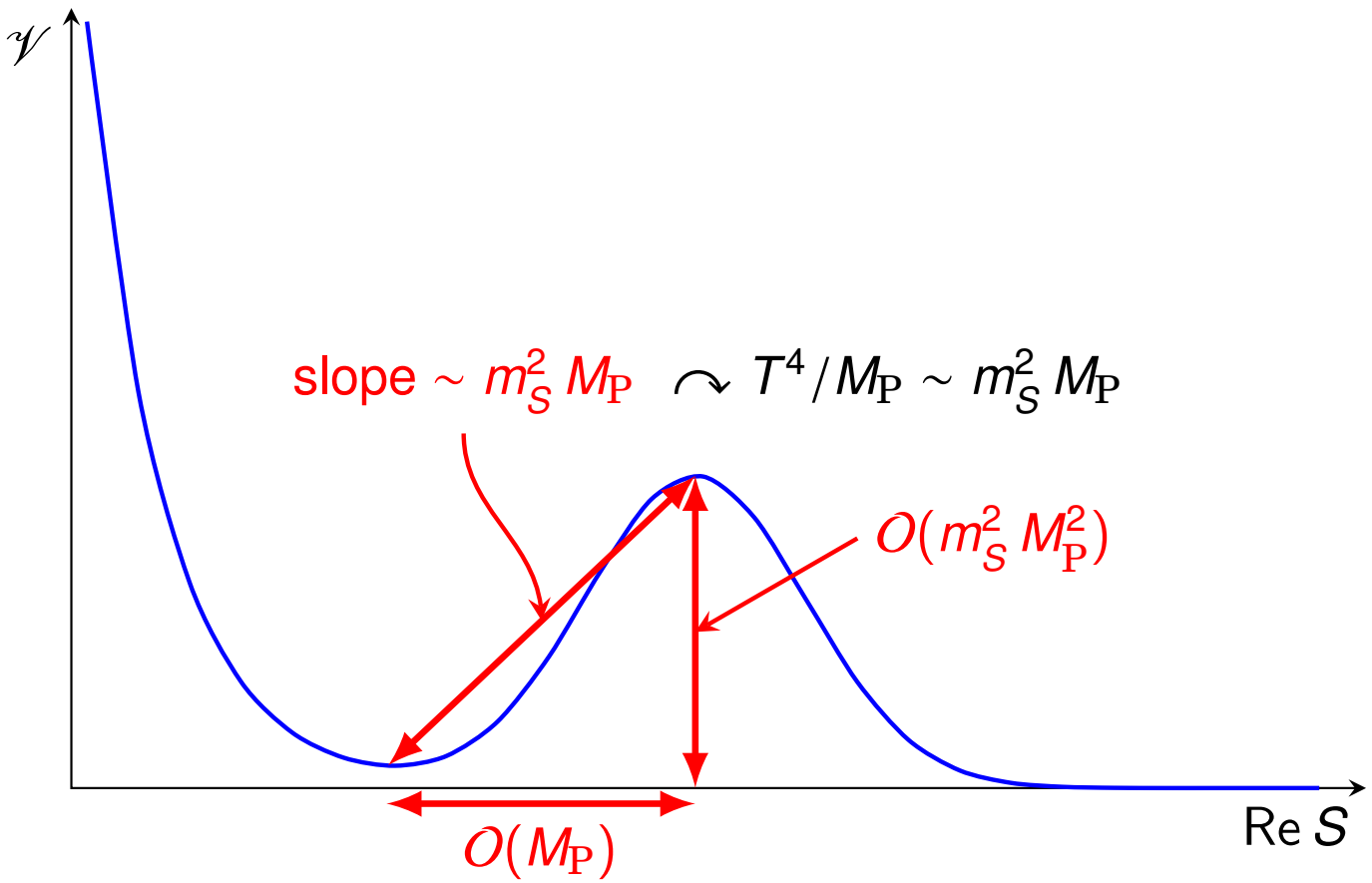

bottom–line:

critical temperature $T_* \sim \sqrt{m_S M_P}$

Discussion

- ☞ if the dilaton has been destabilized, it will run away and cannot come back

model–independent contraint:

$$T_R \lesssim T_* \sim \sqrt{m_S M_{\rm P}}$$

reheating temperature (maximal temperature of the radiation dominated universe)

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Kallosh and Linde (2004)

- the bounds can be circumvented by stabilizing the field combination that fixes the gauge coupling in a different way (i.e. w/ an infinite barrier)

Kane and Winkler (2019)

Constraints

on

flavons

Field–dependent fermion masses

☞ e.g. Froggatt–Nielsen mechanism

Froggatt and Nielsen (1979)

$$\mathscr{L}_{\mathrm{FN}} = \sum_{i,j=1}^{3} y_{ij}^{u} \left(\frac{S}{\Lambda}\right)^{n_{ij}^{u}} \overline{Q}_i \, \widetilde{\Phi} \, u_j + \sum_{i,j=1}^{3} y_{ij}^{d} \left(\frac{S}{\Lambda}\right)^{n_{ij}^{d}} \overline{Q}_i \, \Phi \, d_j + \text{h.c.}$$

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$$\mathscr{V}_S = -\mu_S^2 |S|^2 + \lambda_S |S|^4 + \lambda_{S\Phi} |S|^2 |\Phi|^2 + \mathrm{U}(1)_{\mathrm{FN}} \text{ breaking terms}$$

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- effective potential

$$\alpha \;=\; \gamma\, \frac{\partial T_Y}{\partial \varepsilon} \;\sim\; 10^{-2}$$

$$\mathscr{V}_{\rm eff}(\sigma, T) \;=\; \gamma\, T_Y\, T^4 + \alpha\, T^4 \frac{\sigma}{\Lambda} + \frac{m_\sigma^2(T)}{2}\, \sigma^2 + \frac{\kappa}{3!}\, \sigma^3 + \frac{\lambda_S}{4}\, \sigma^4 + \ldots$$

Flavon dynamics

Lillard, Ratz, Tait, and Trojanowski (2018)

- the flavon gets driven away from its $T = 0$ minimum until it gets stopped by the mass term or Hubble friction

$$\Delta\sigma \simeq -\alpha \frac{T^4}{\Lambda\, m_{\rm eff}^2} \qquad \text{where } m_{\rm eff}^2 = 6H^2 + m_\sigma^2$$

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- as the temperature decreases, the flavon undergoes oscillations around the $T = 0$ minimum, which behave like nonrelativistic matter

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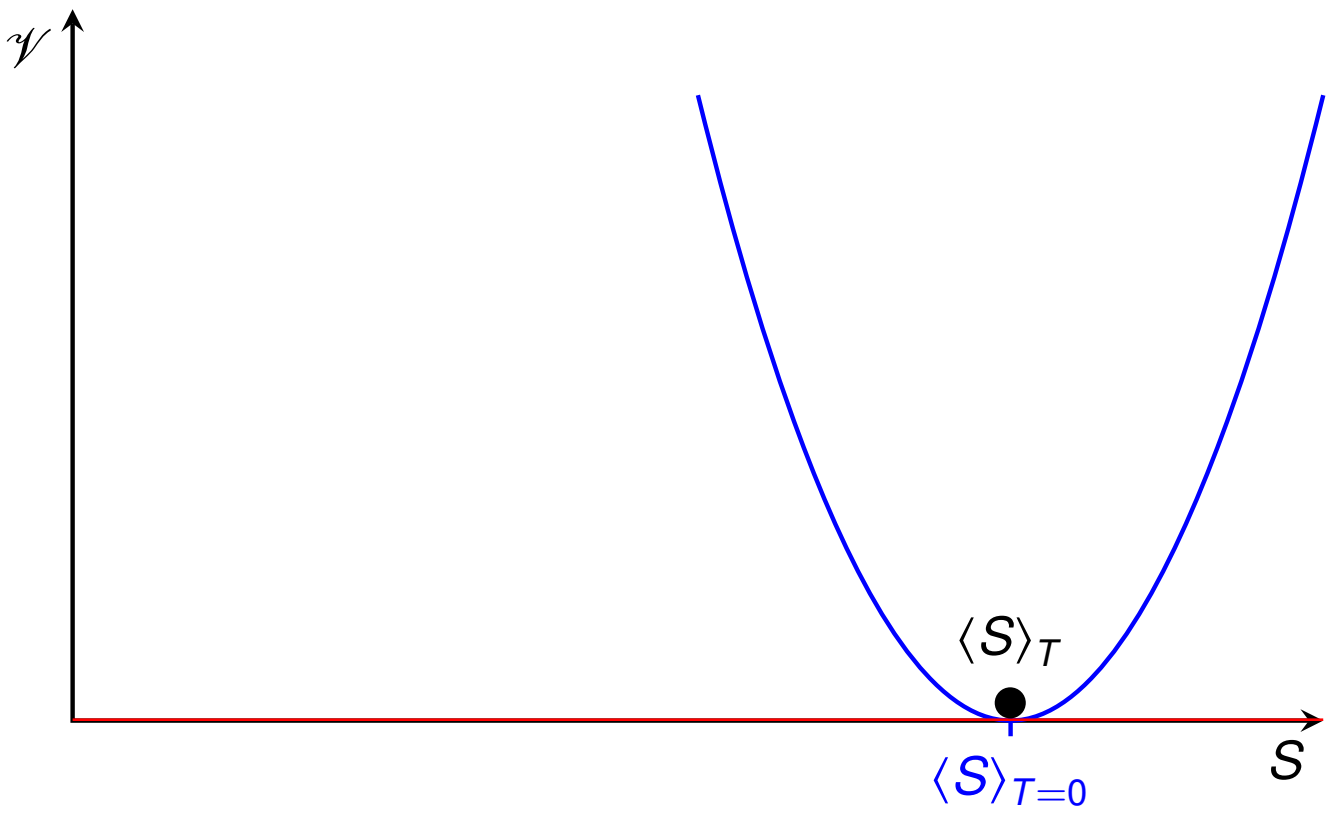

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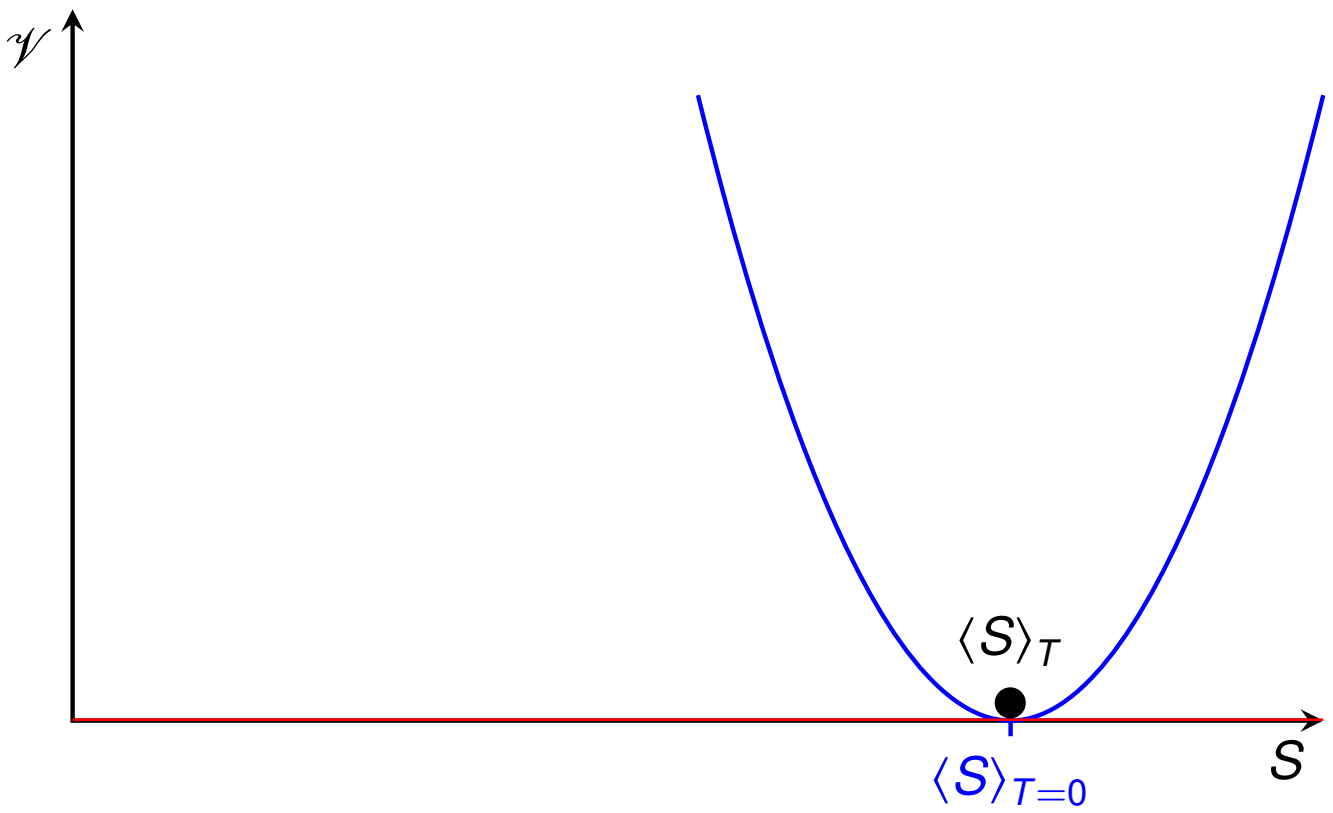

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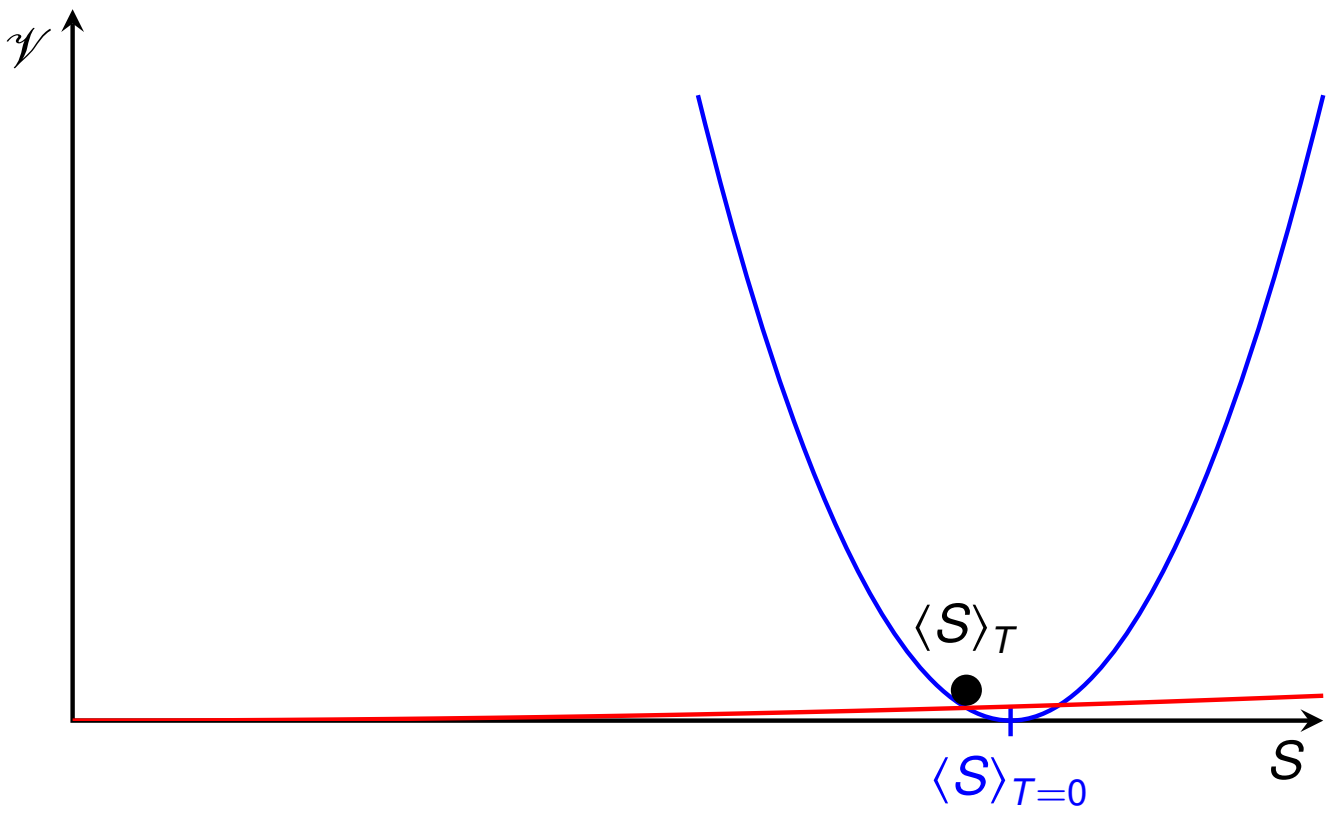

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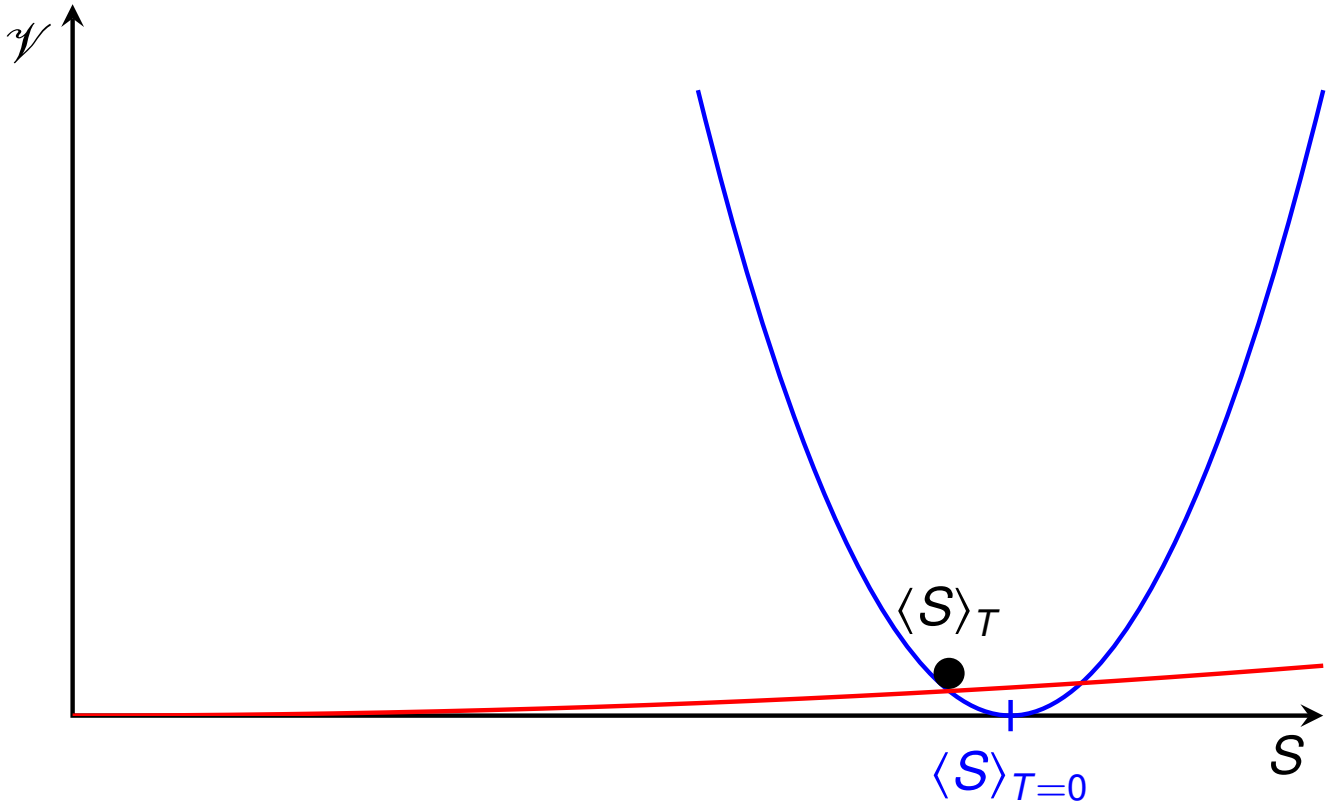

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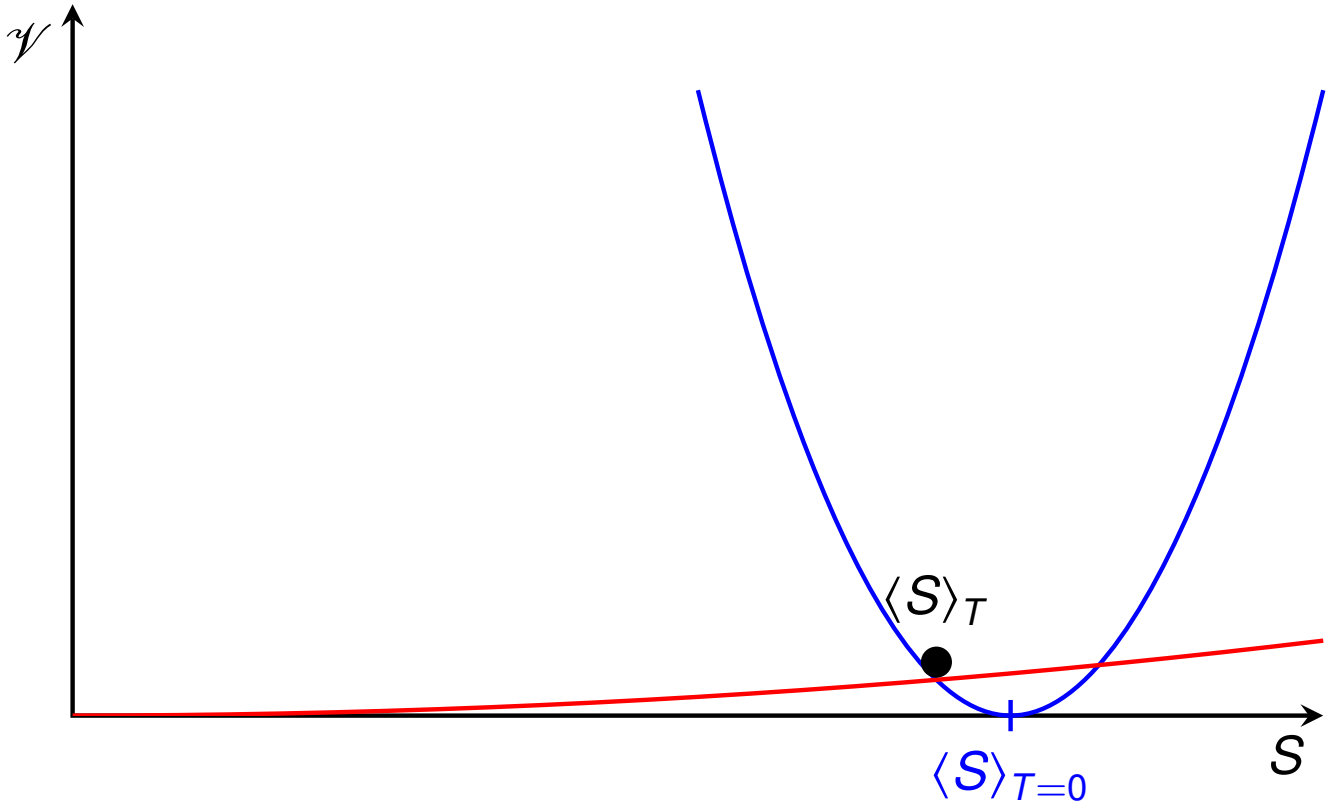

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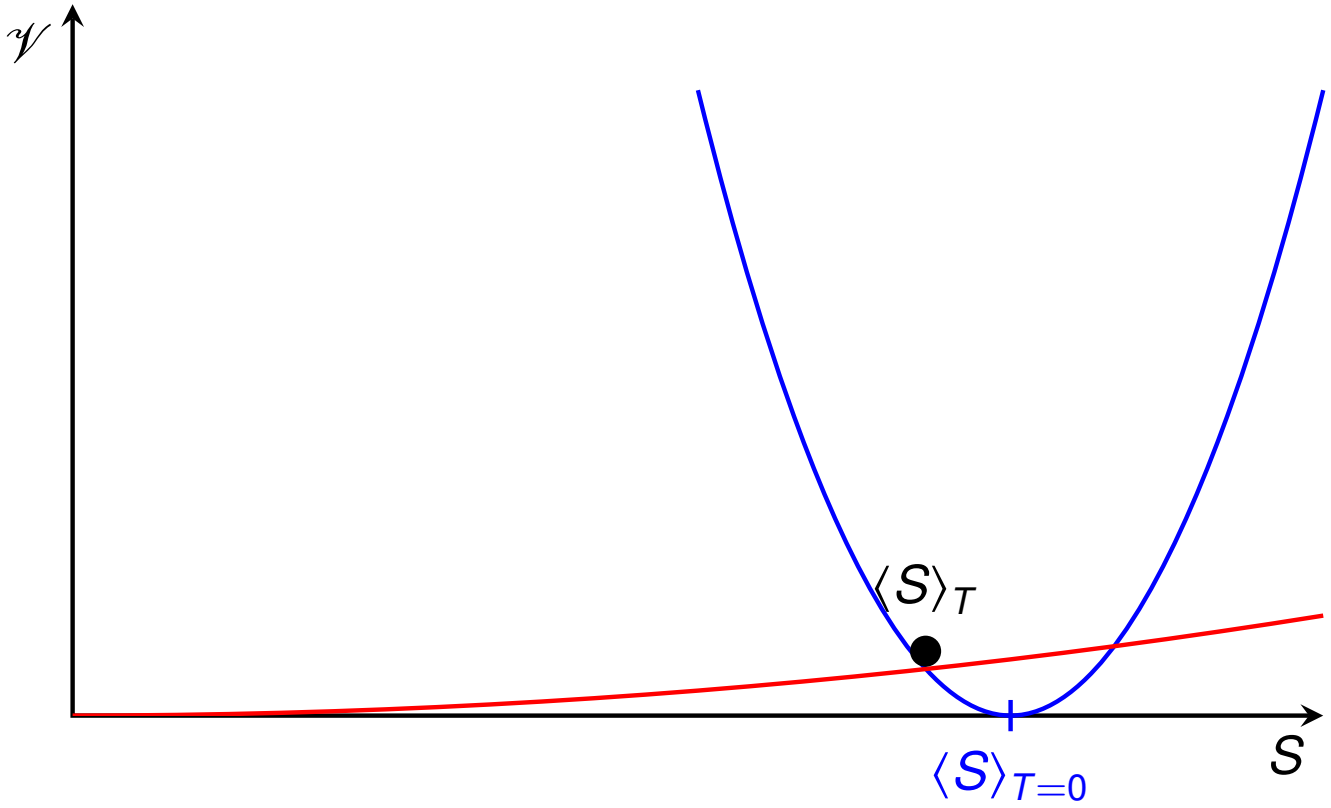

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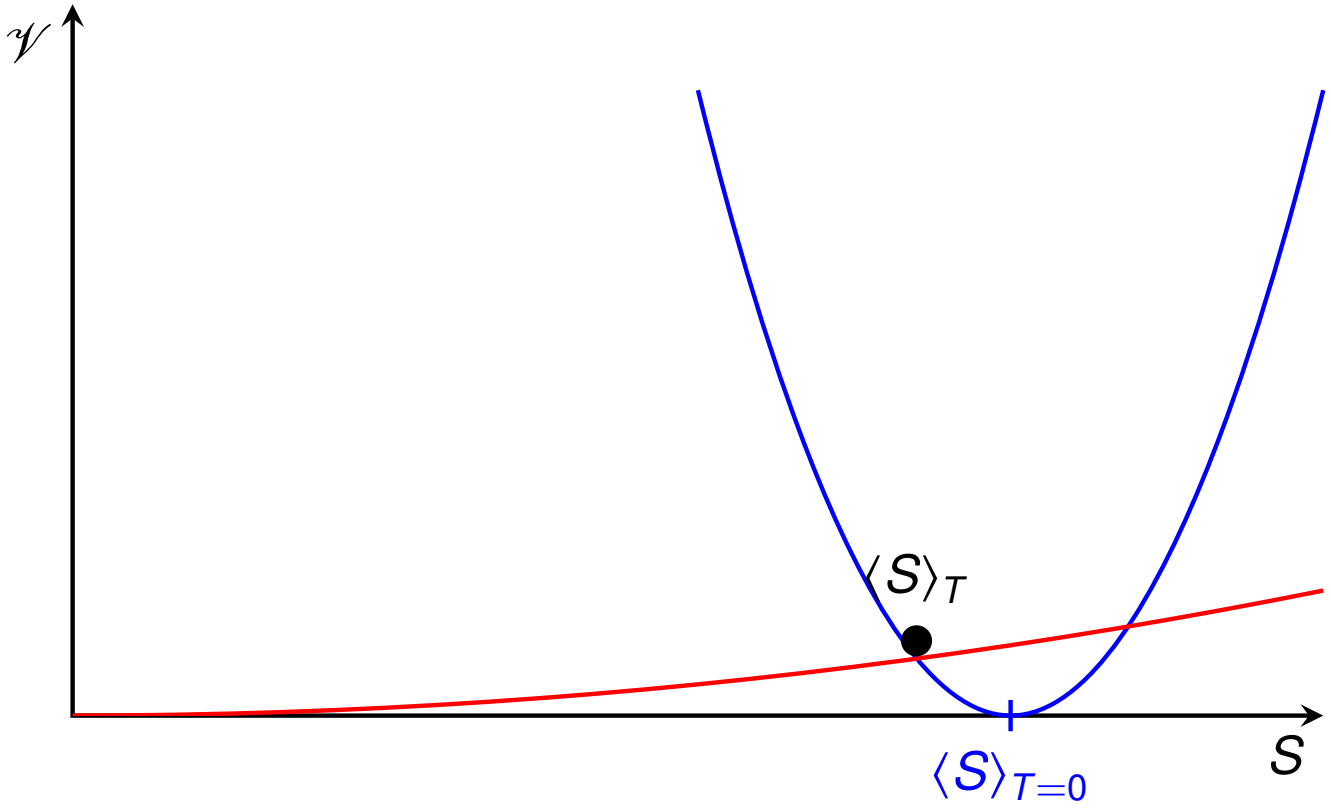

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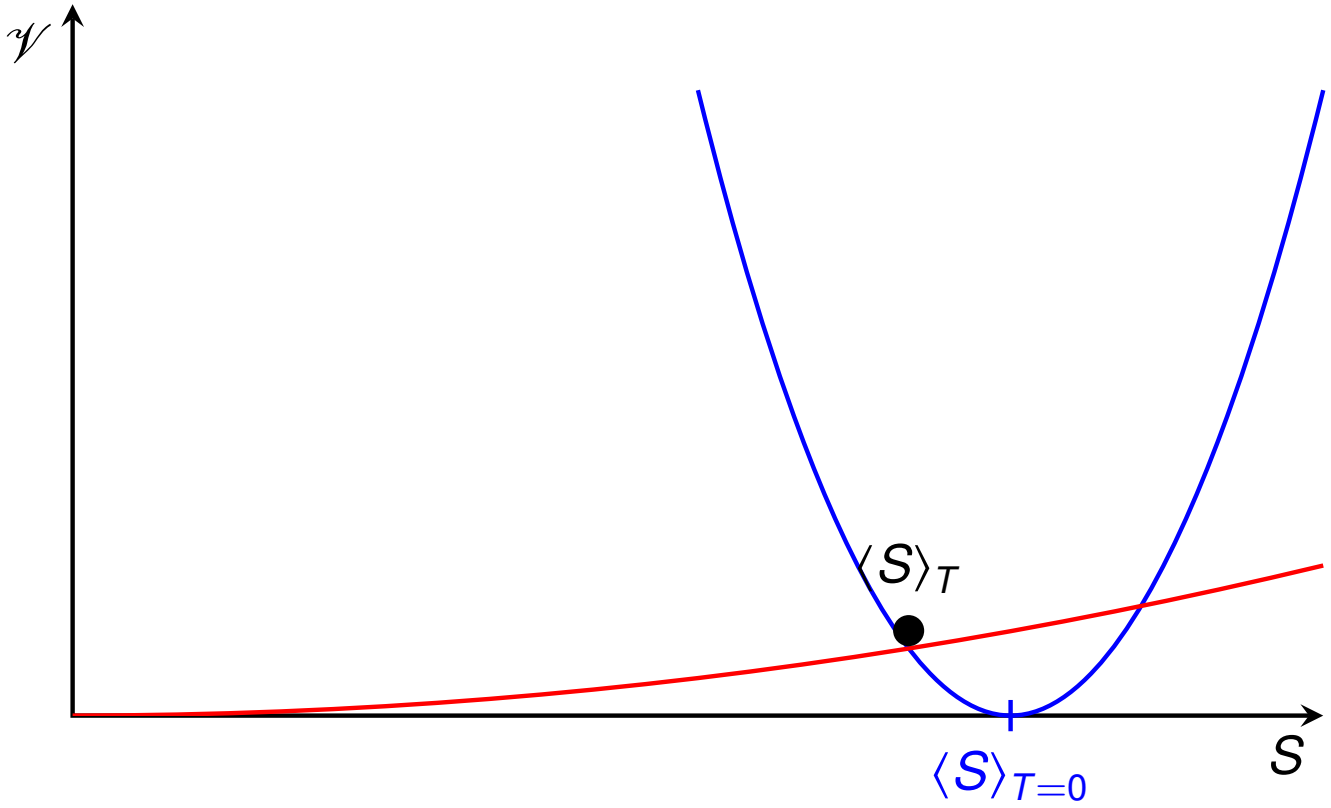

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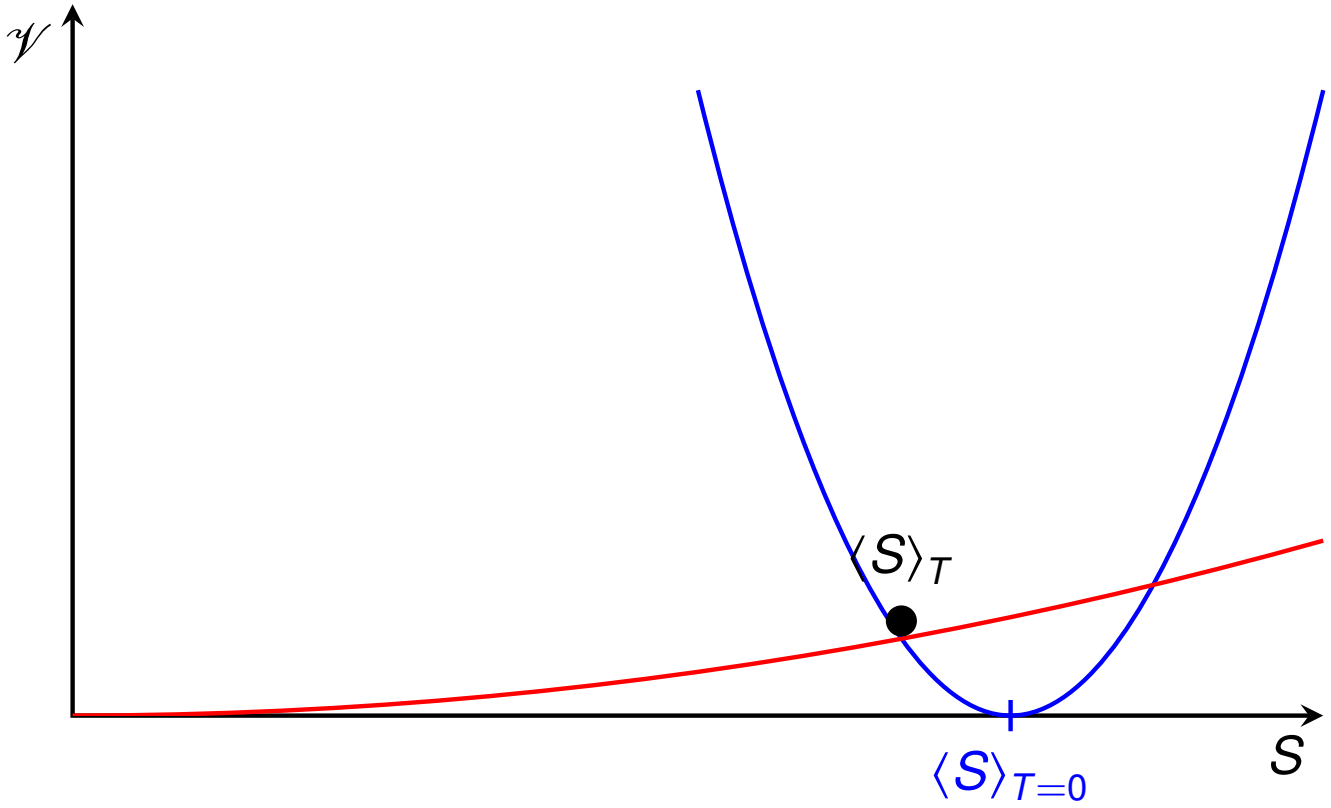

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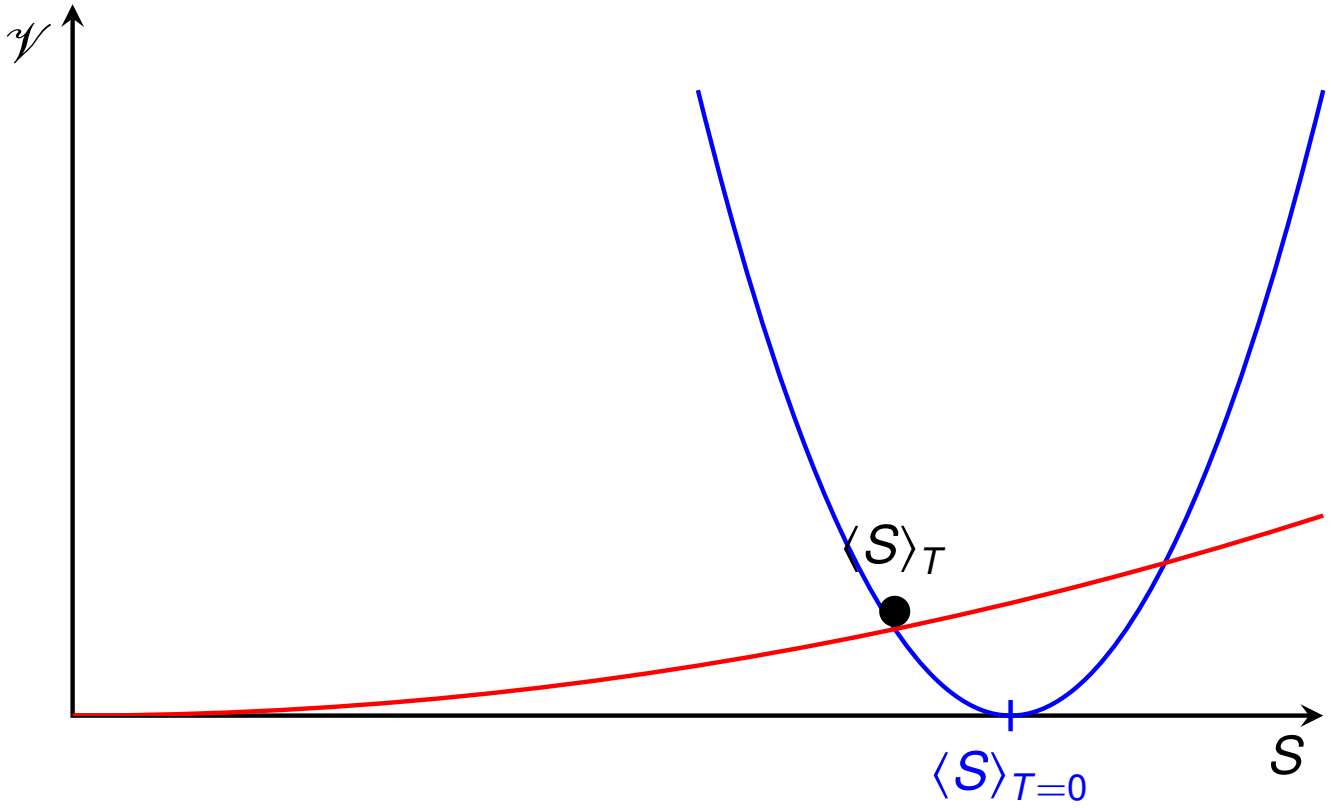

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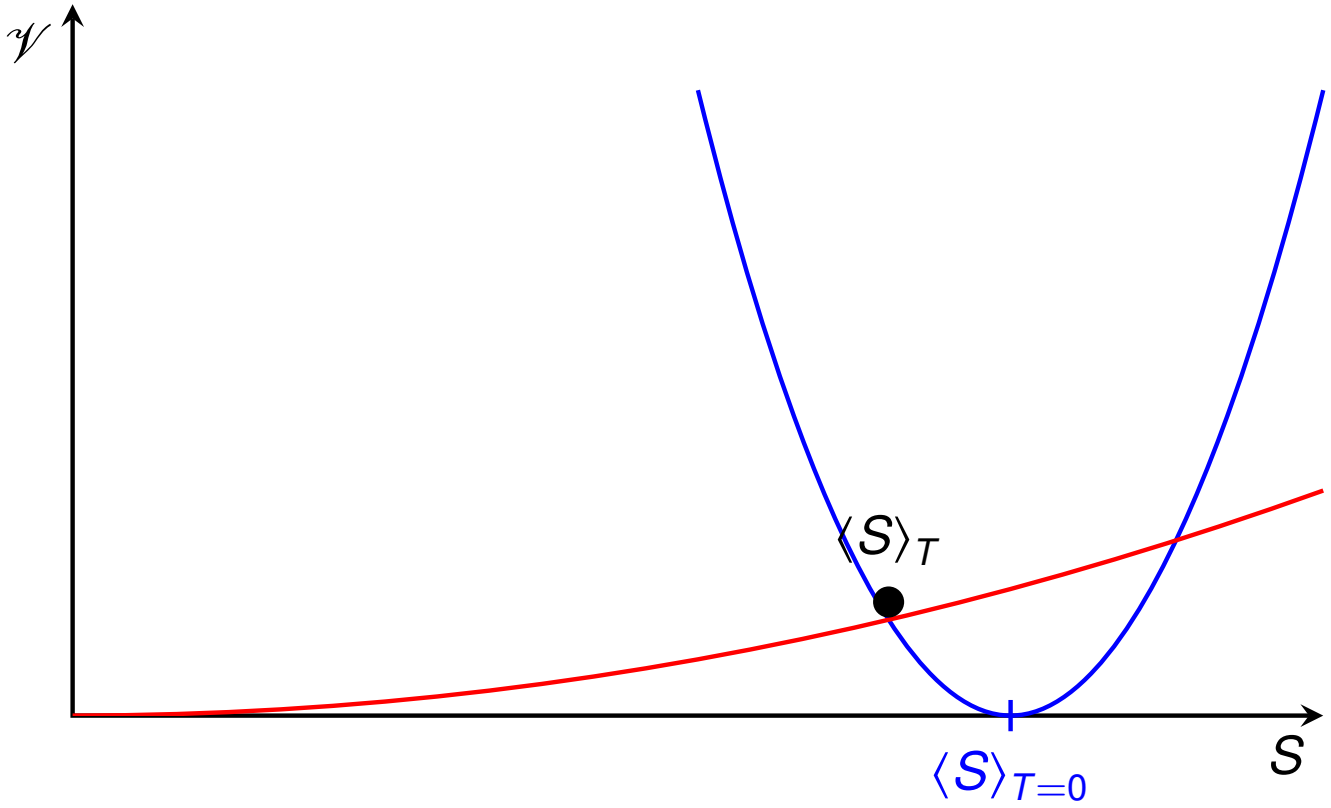

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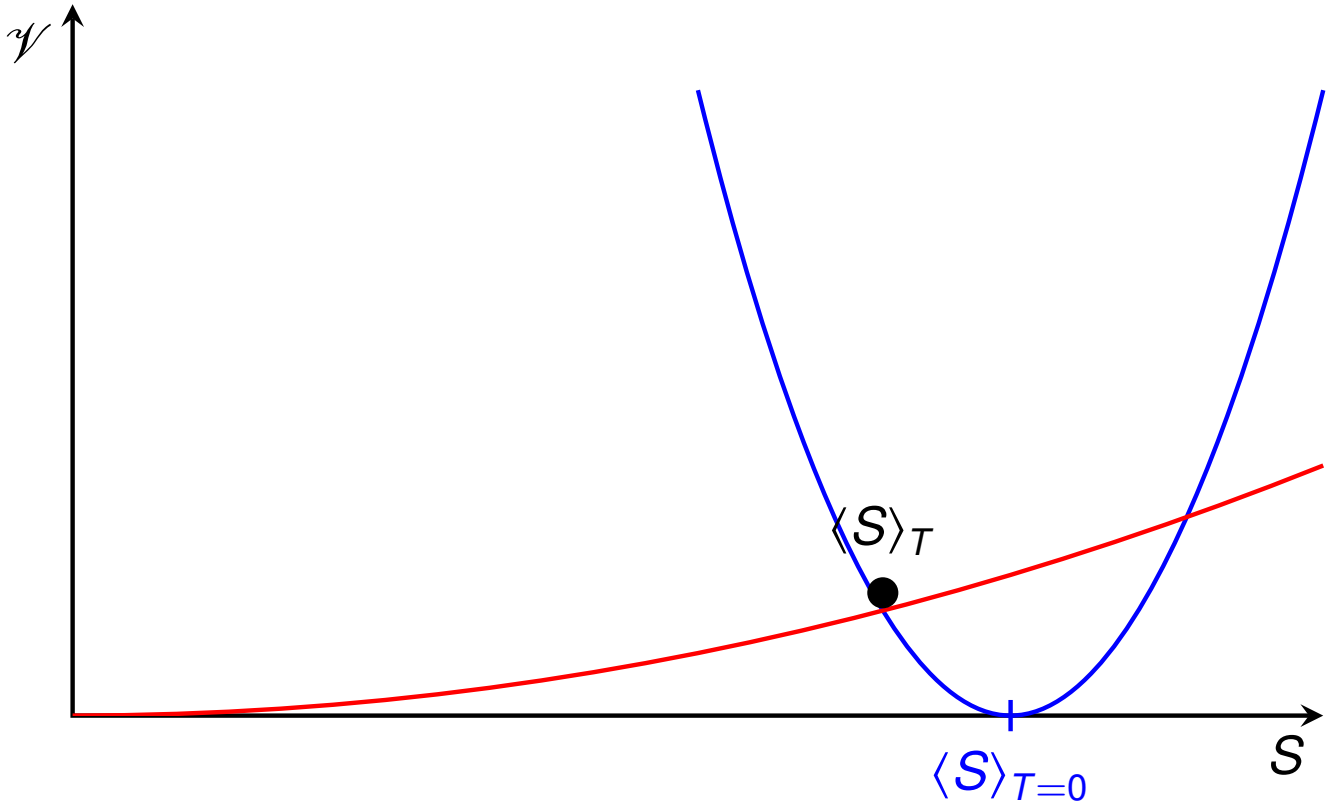

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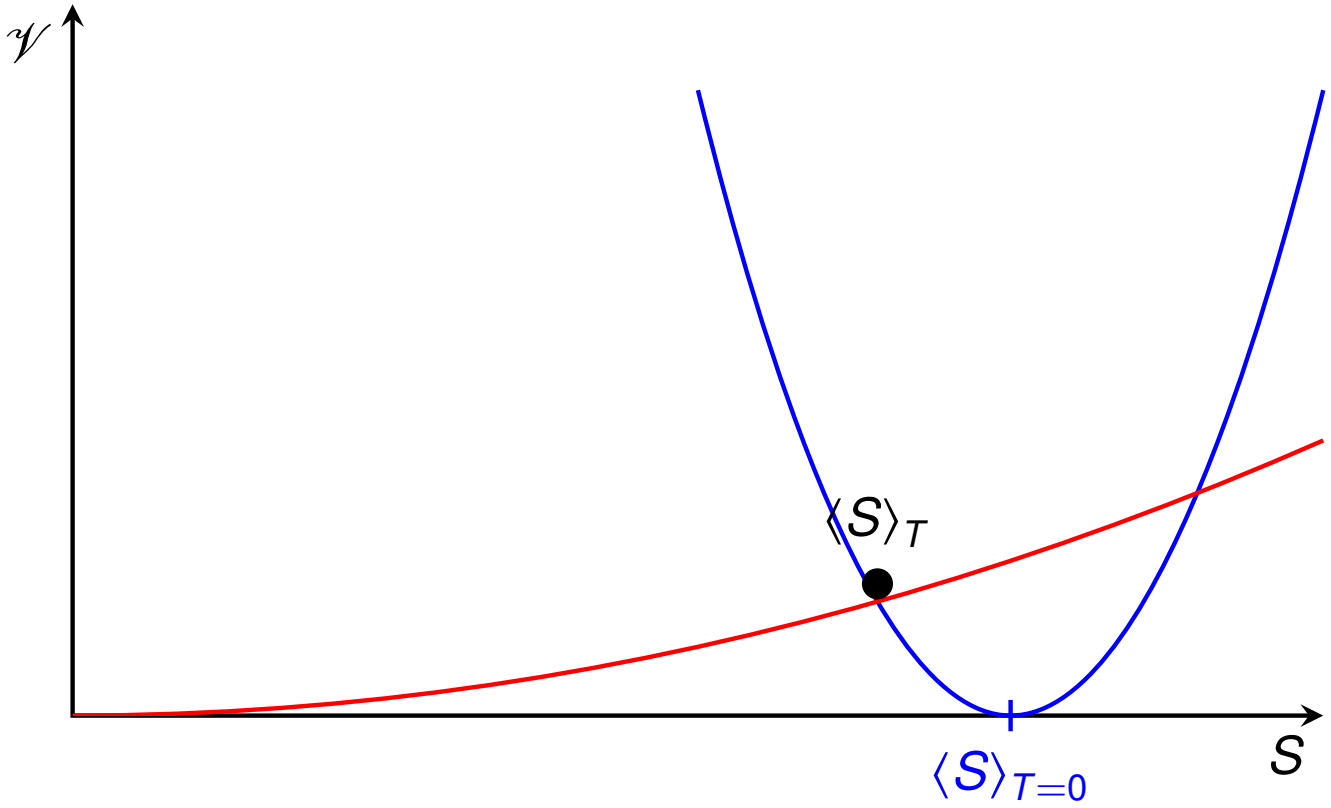

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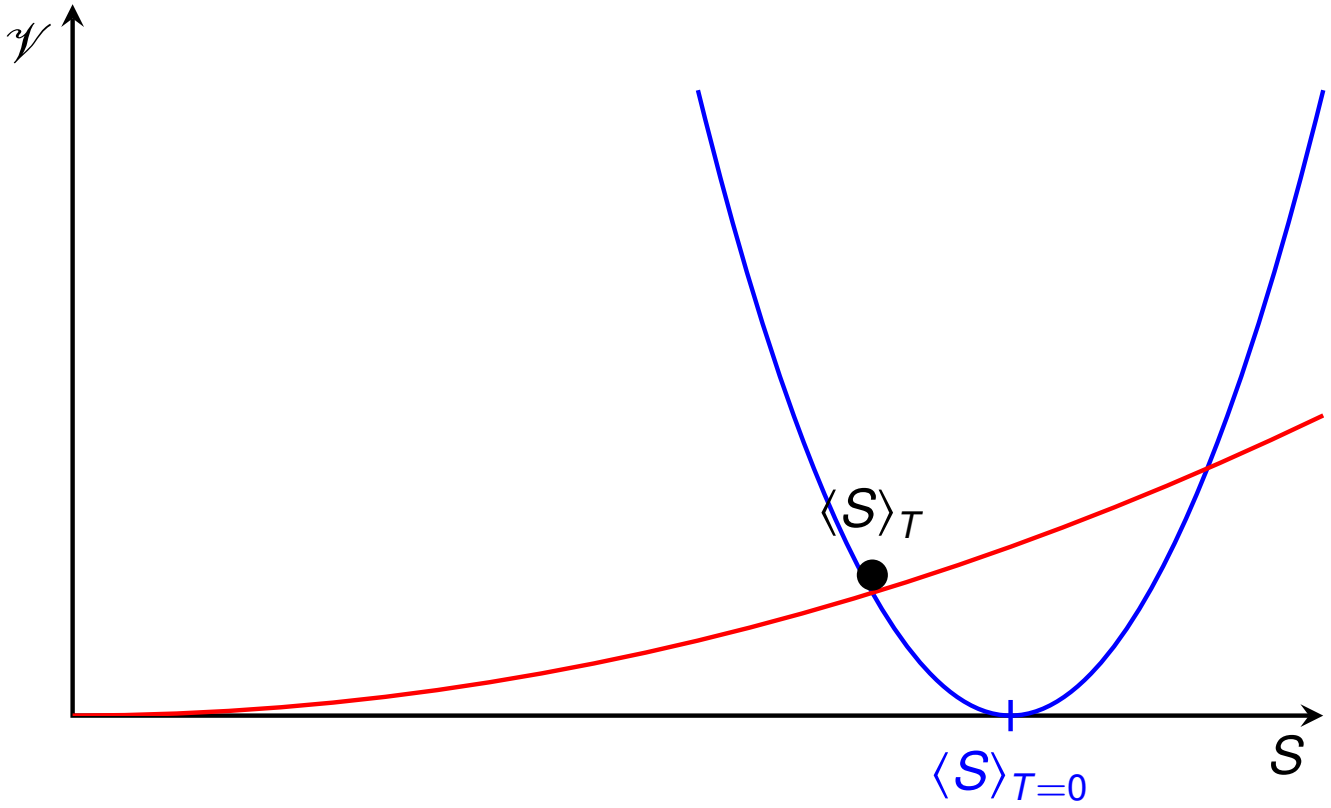

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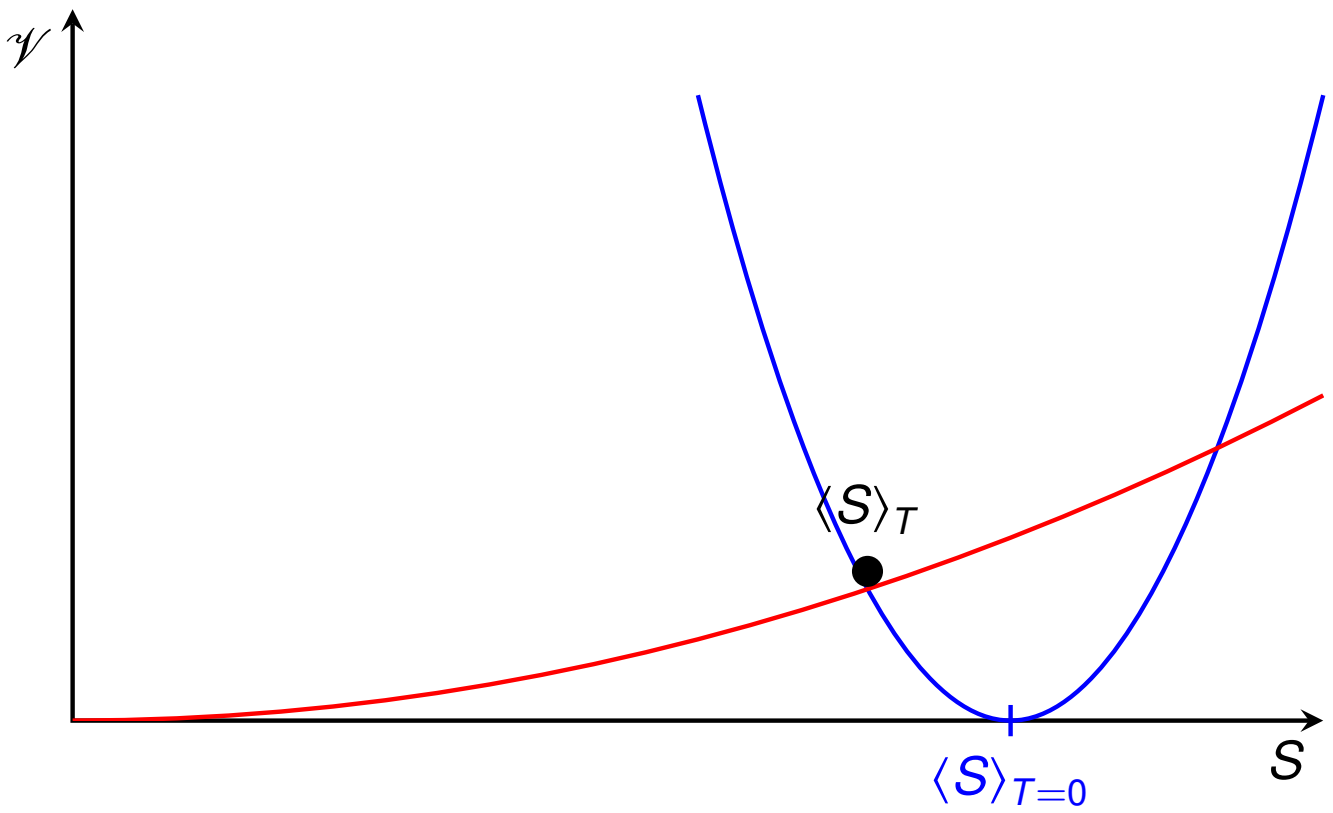

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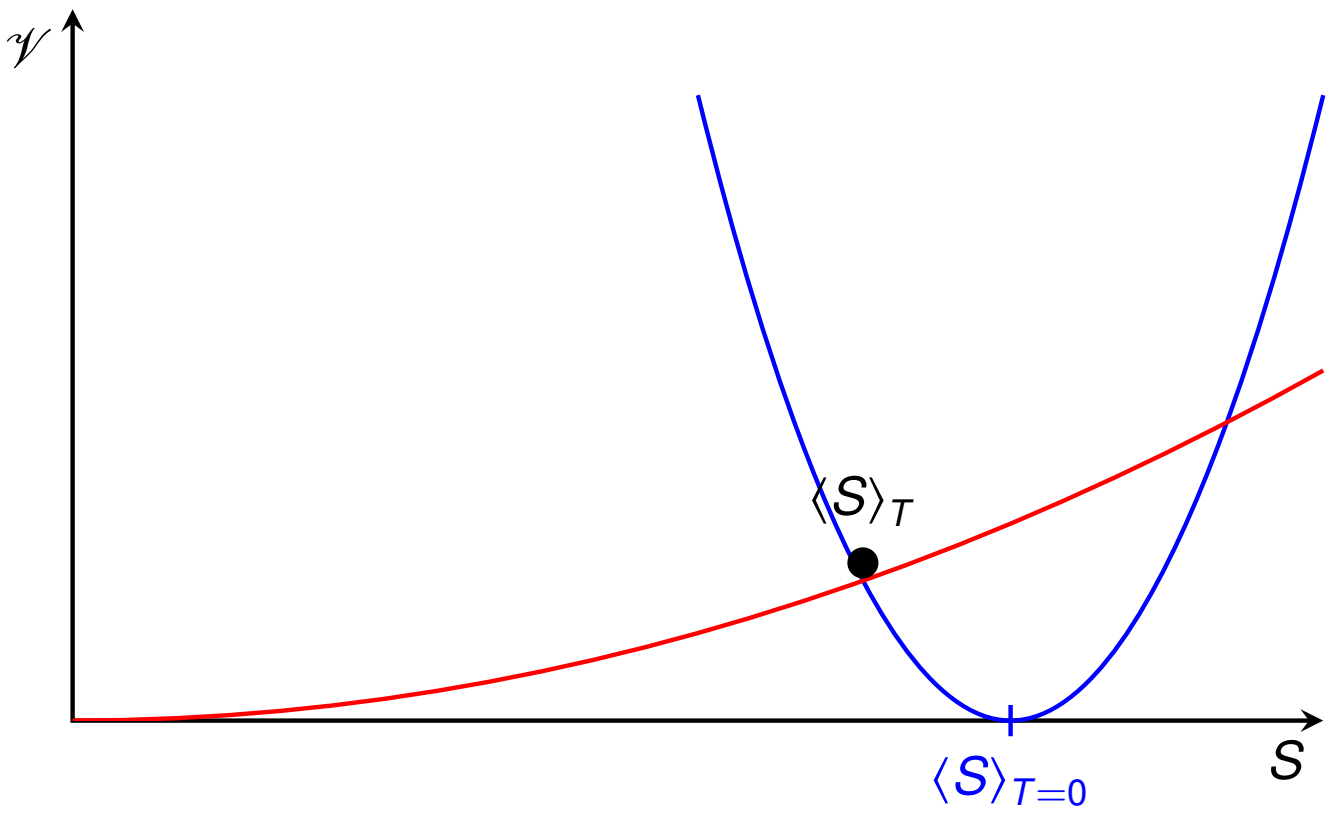

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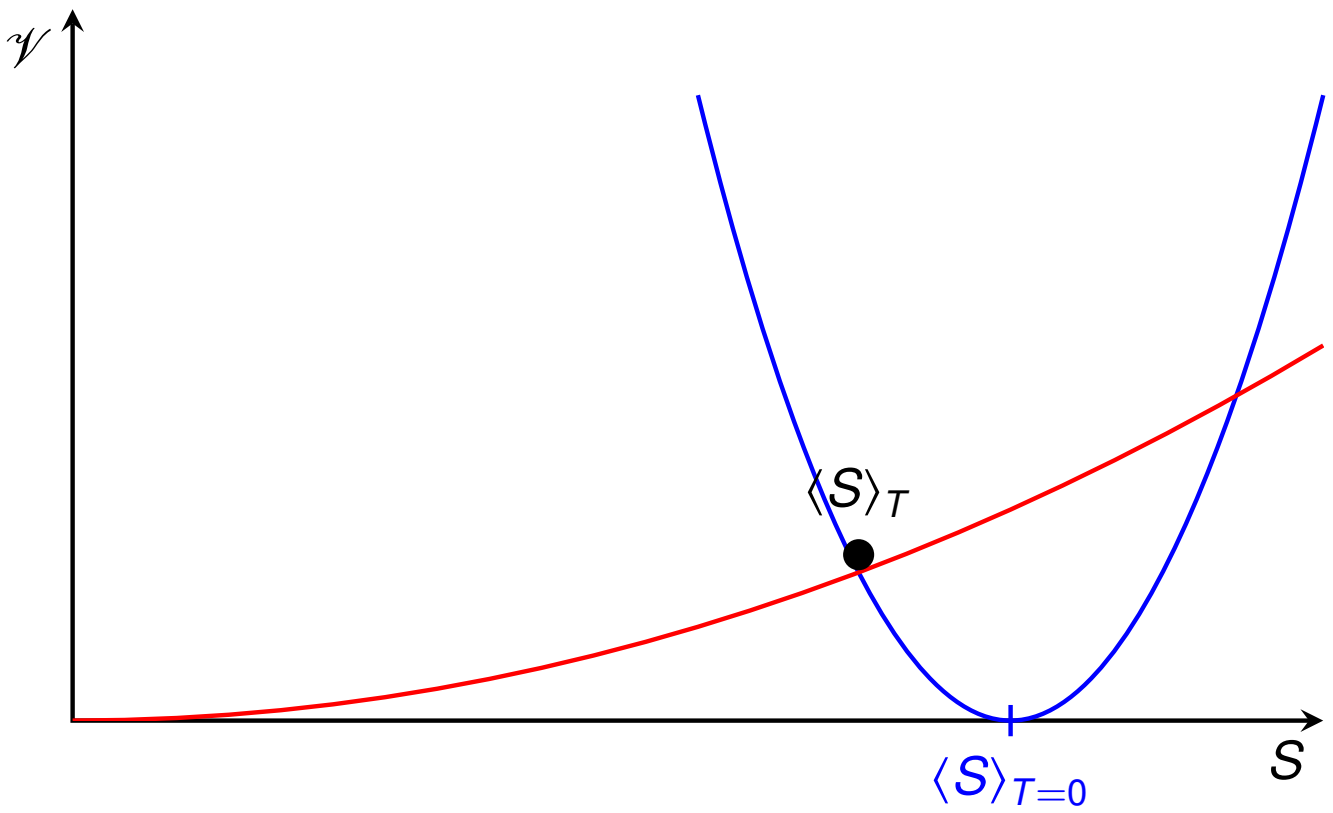

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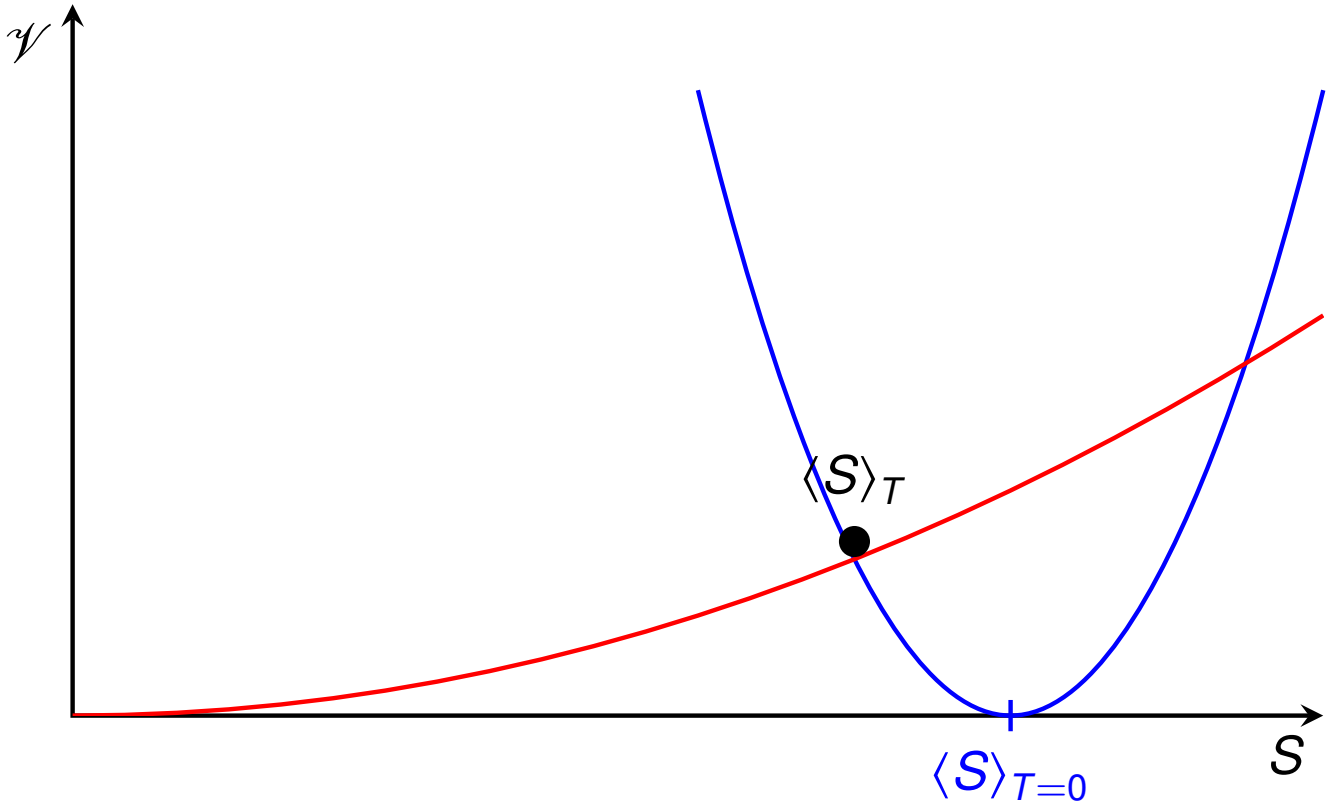

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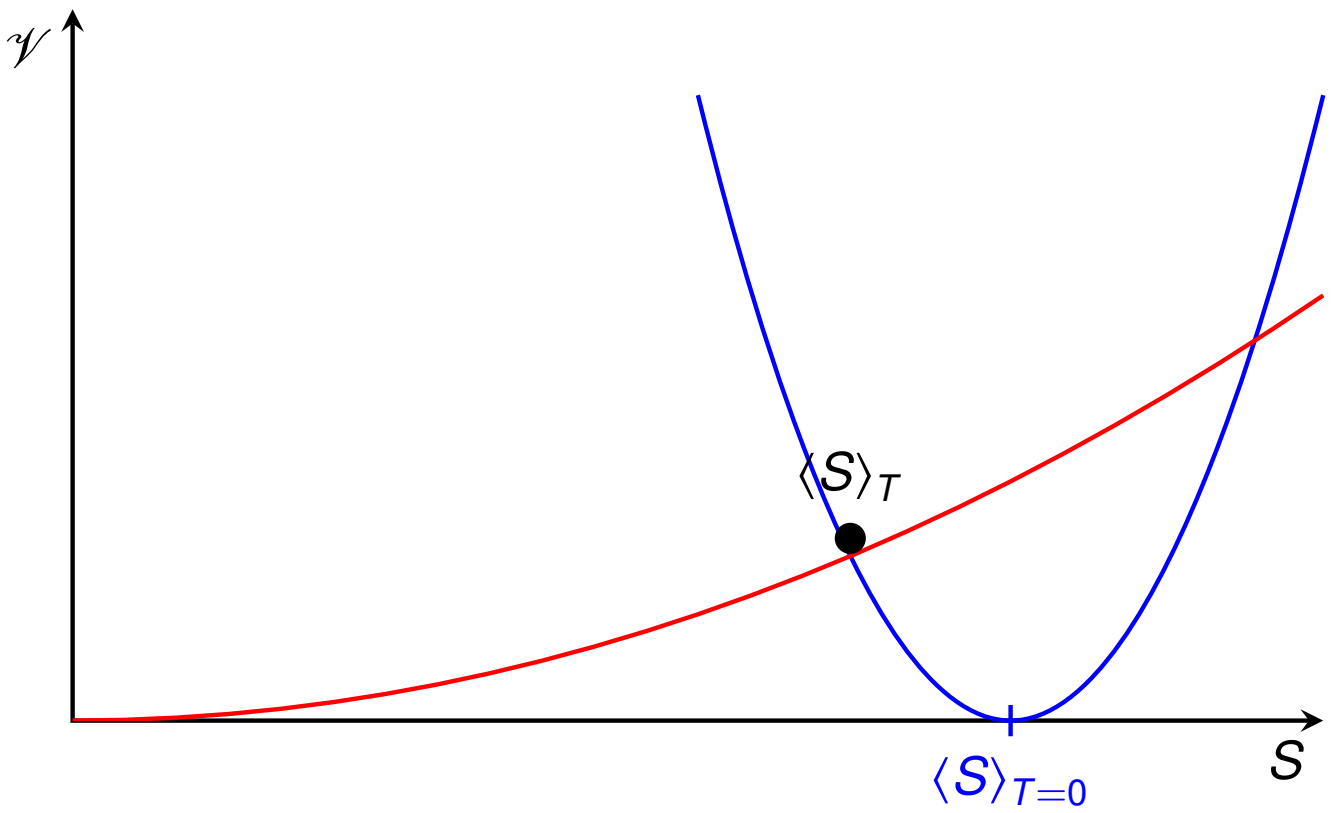

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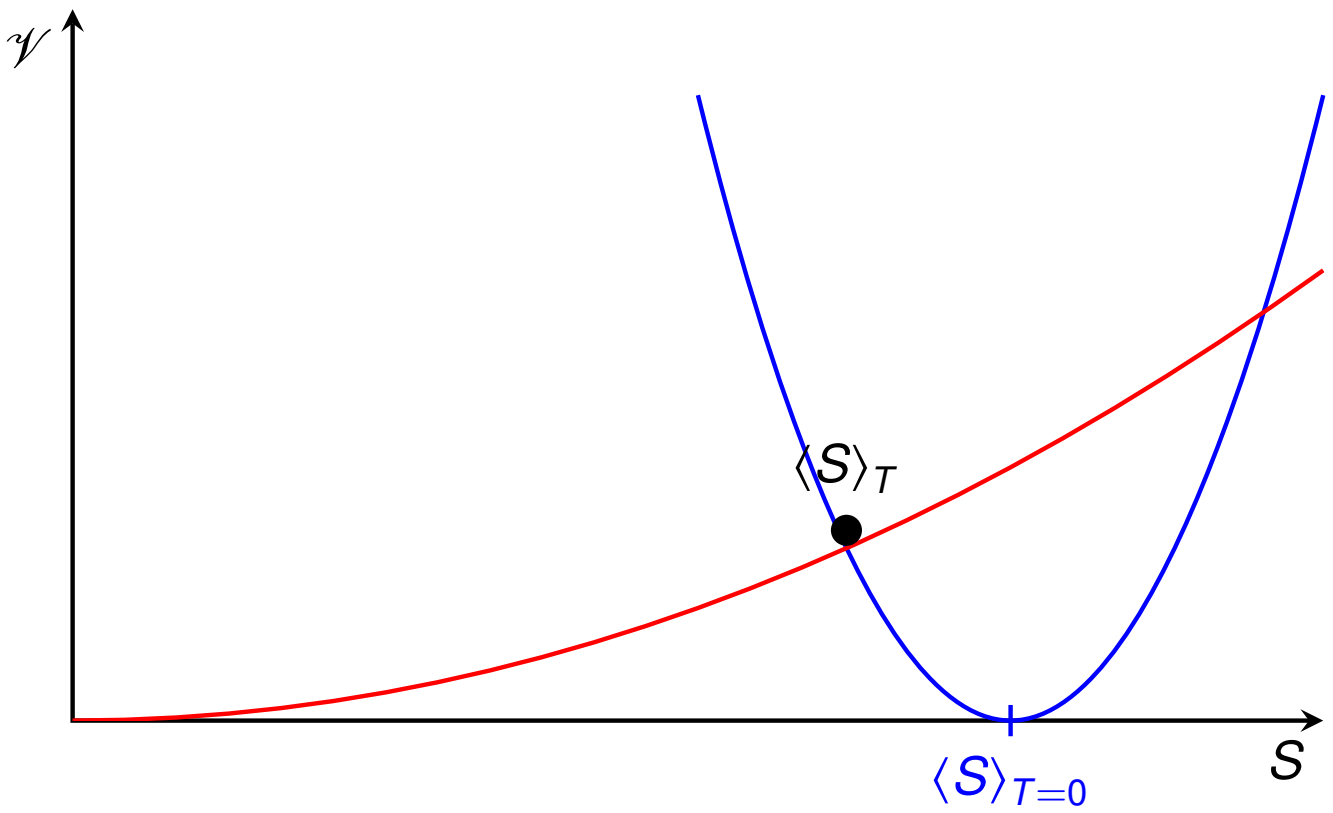

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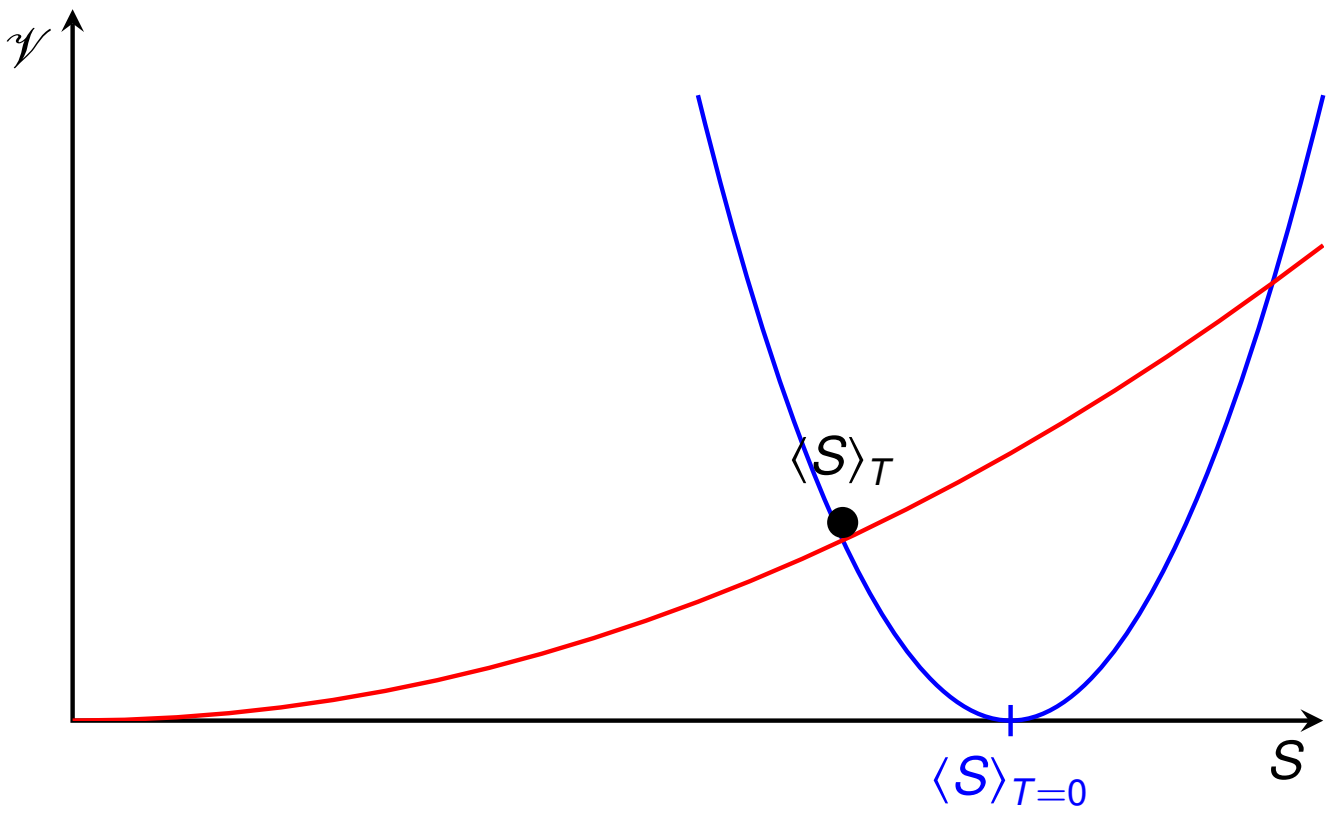

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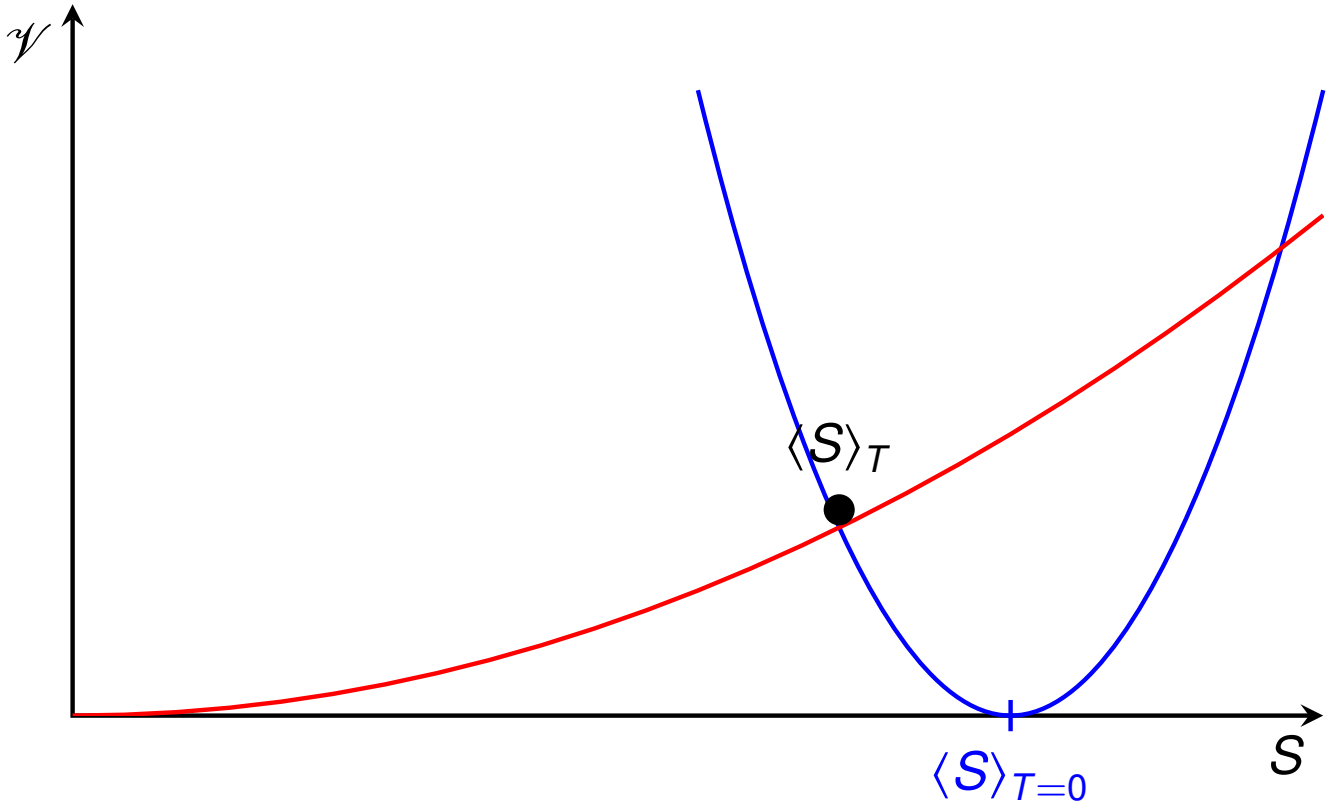

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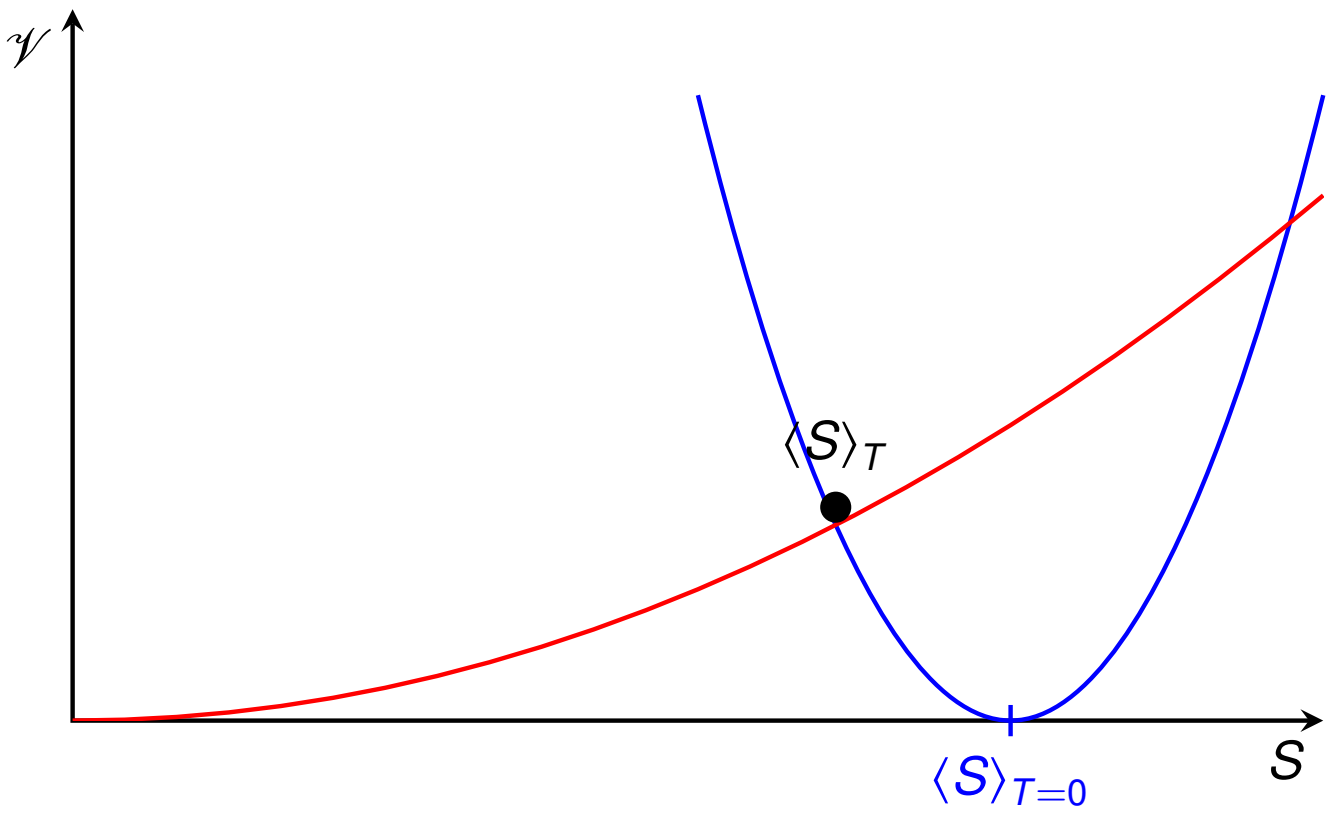

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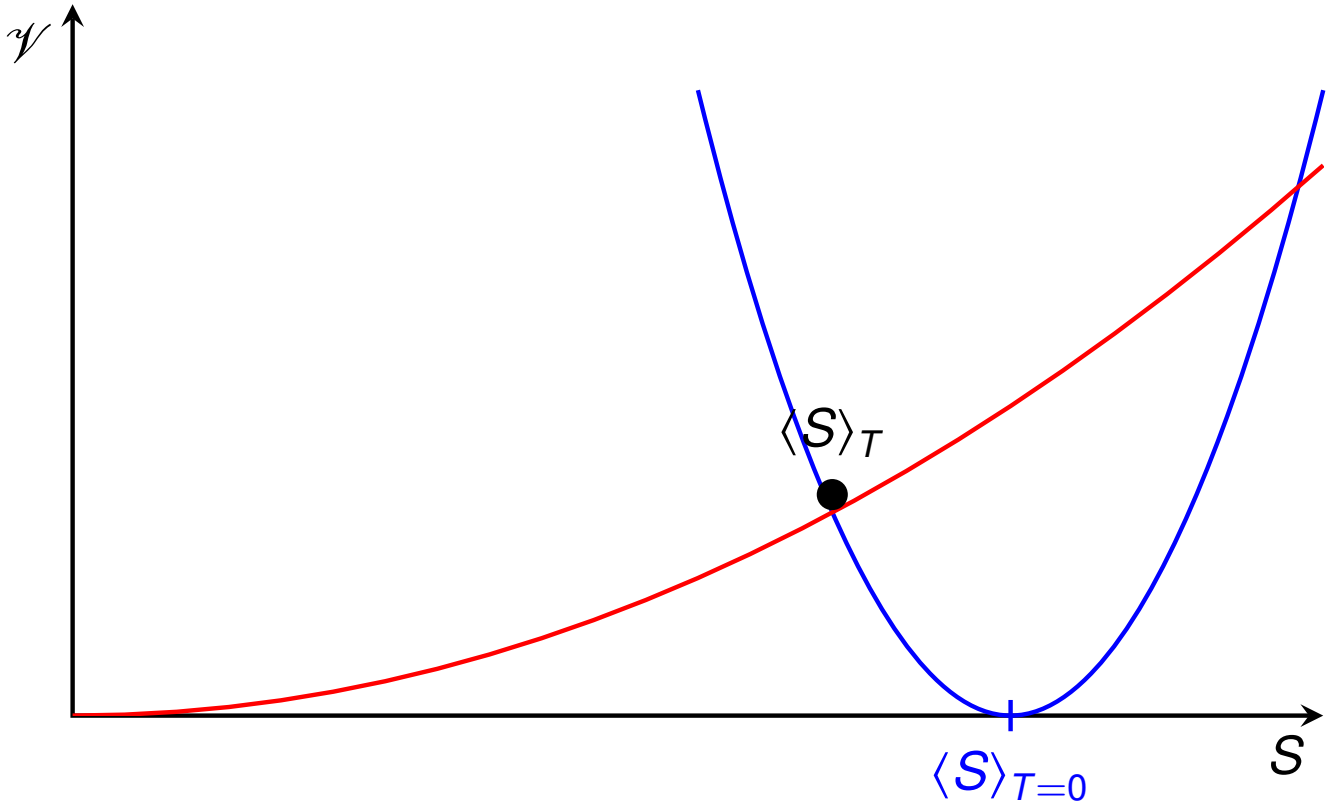

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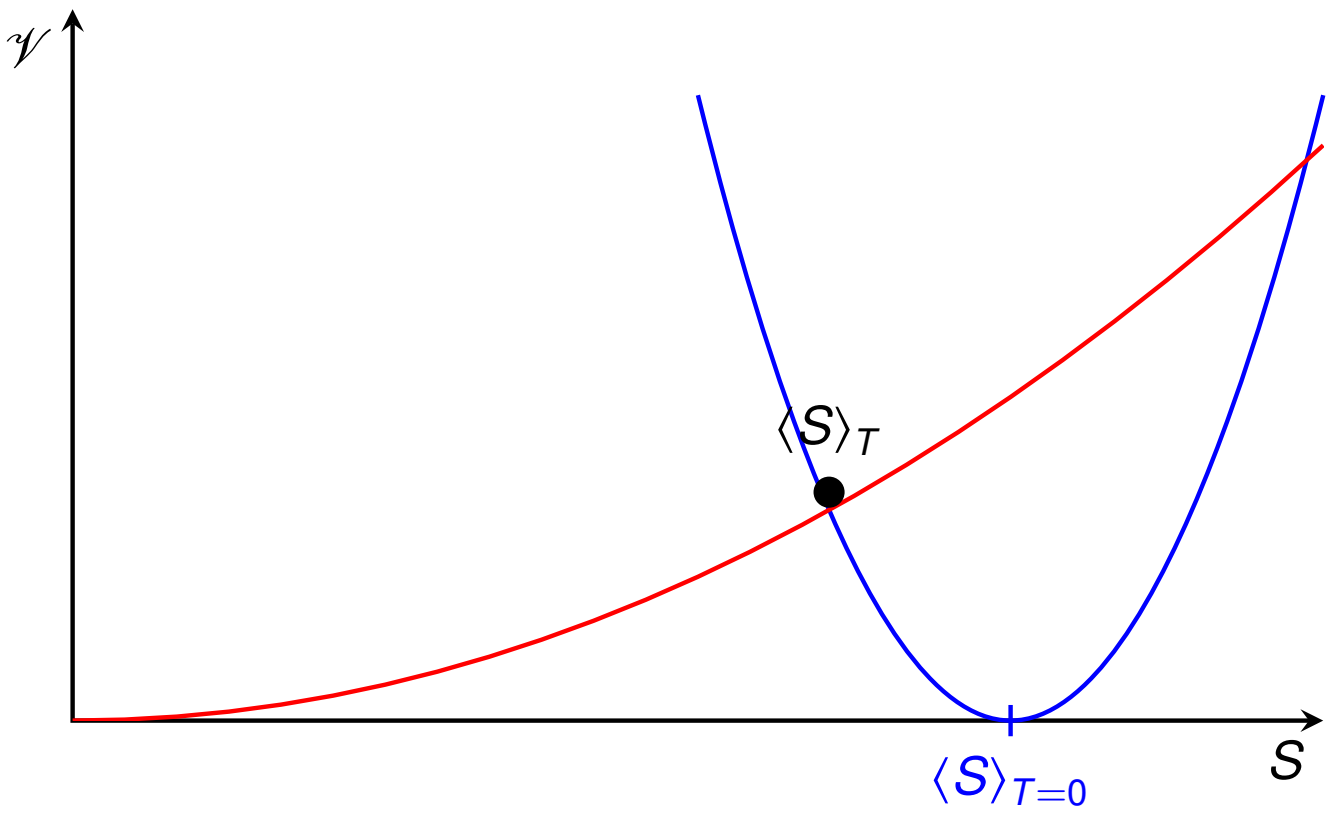

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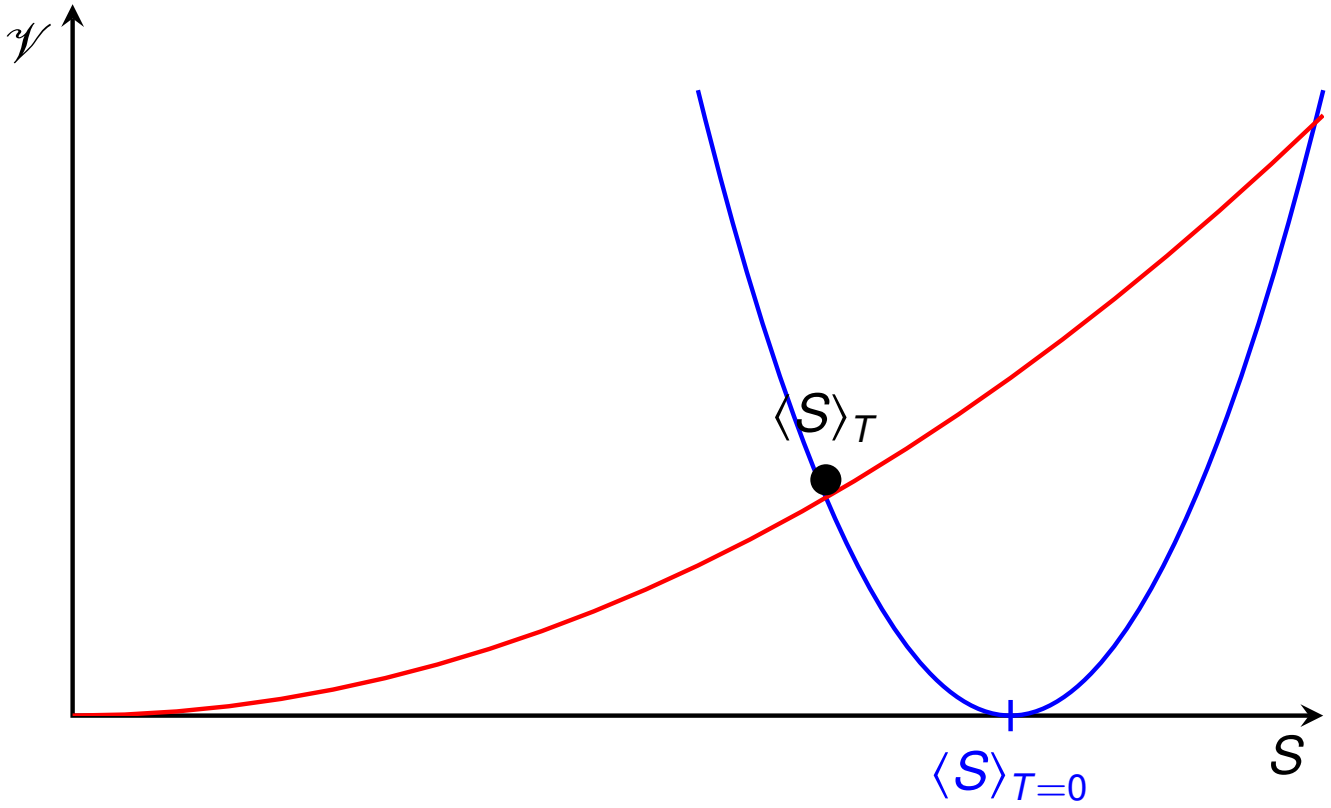

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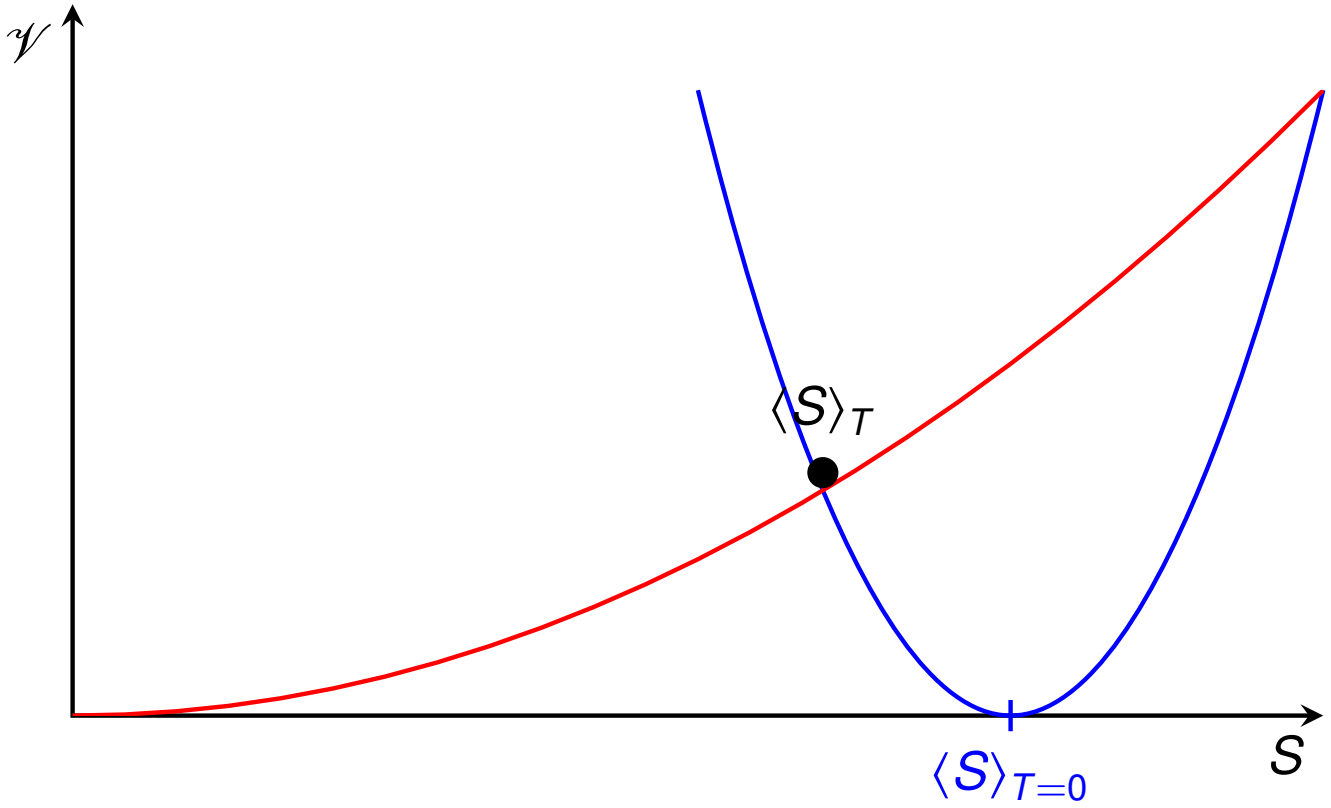

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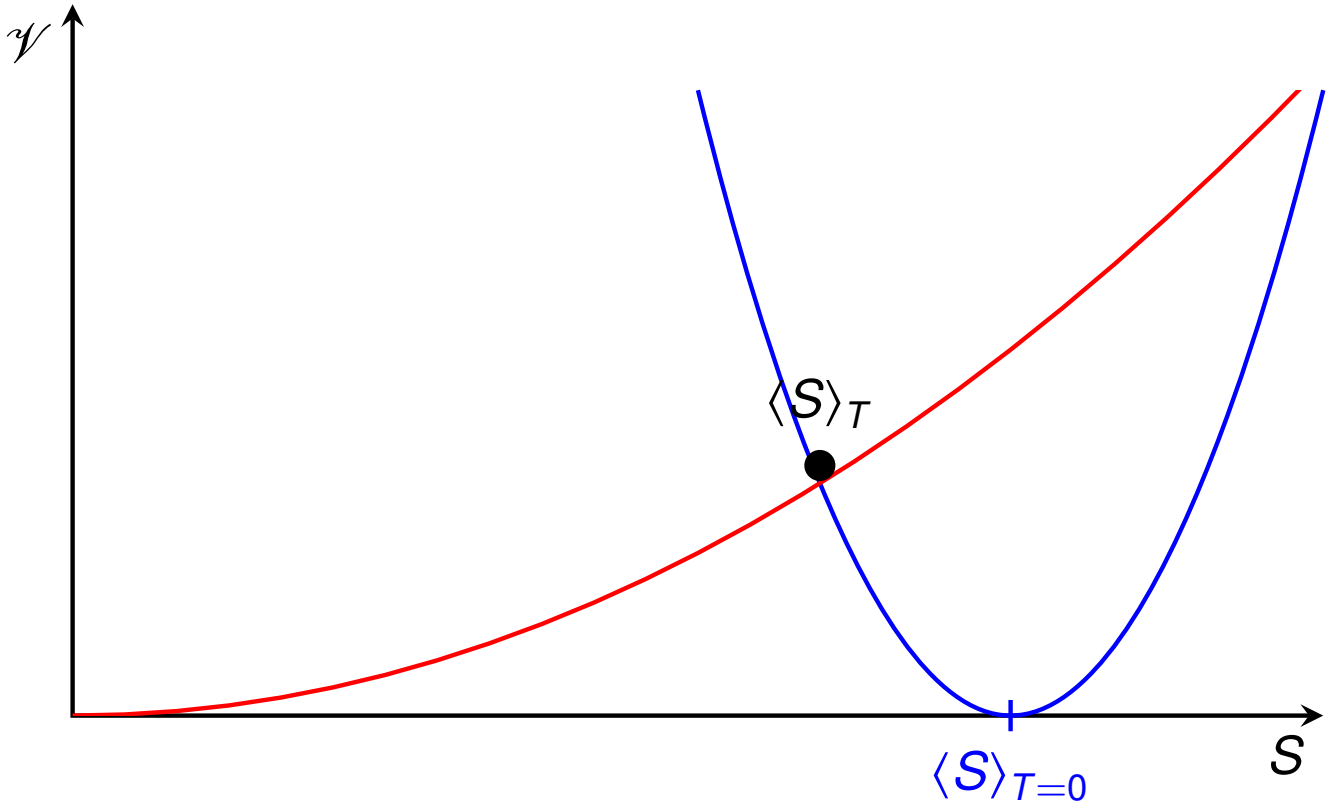

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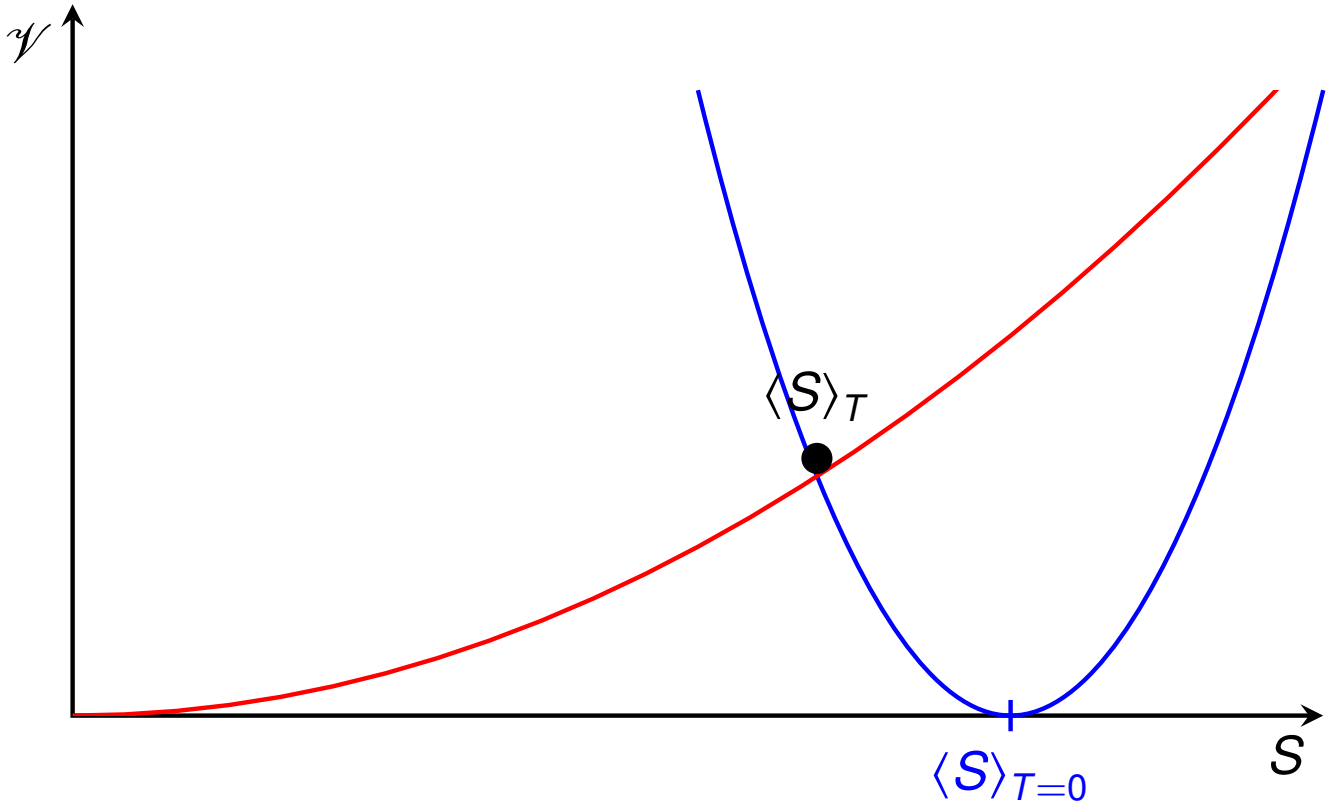

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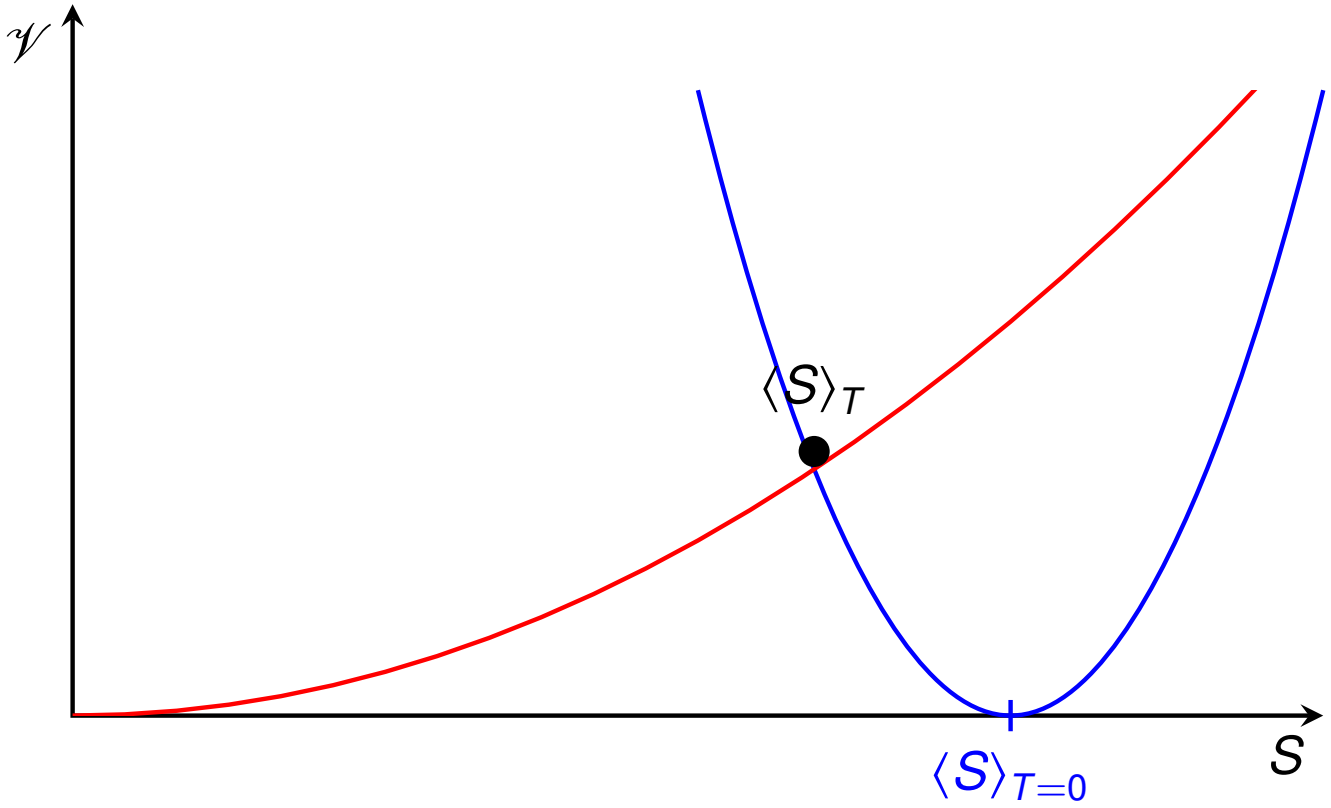

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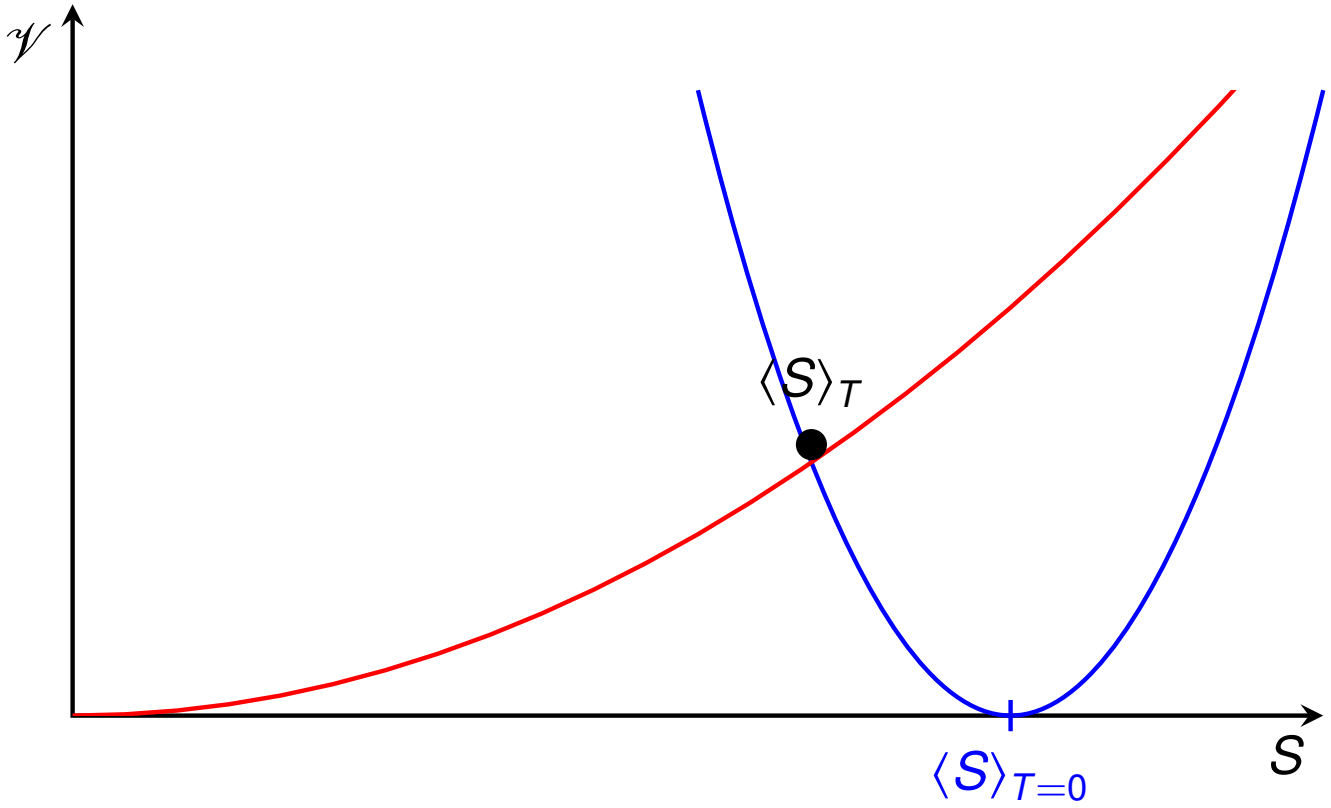

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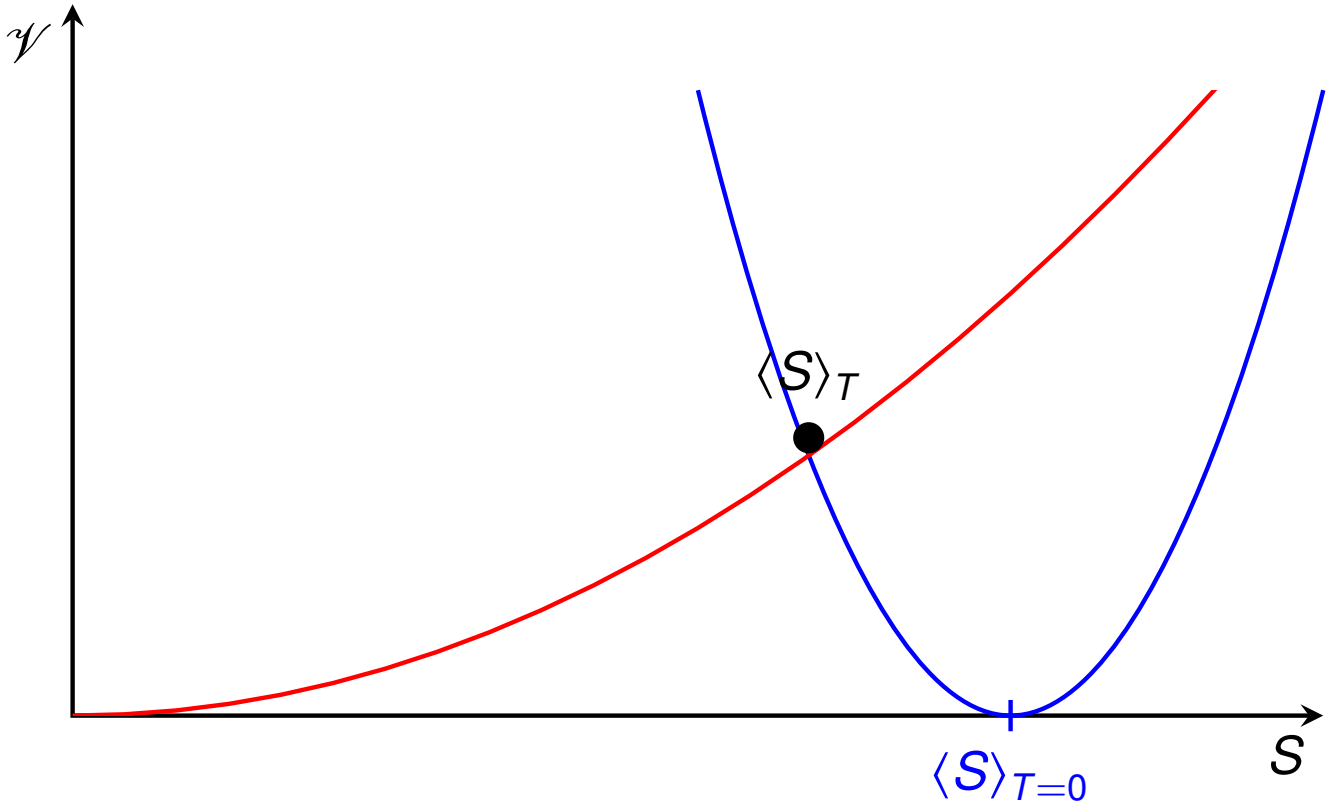

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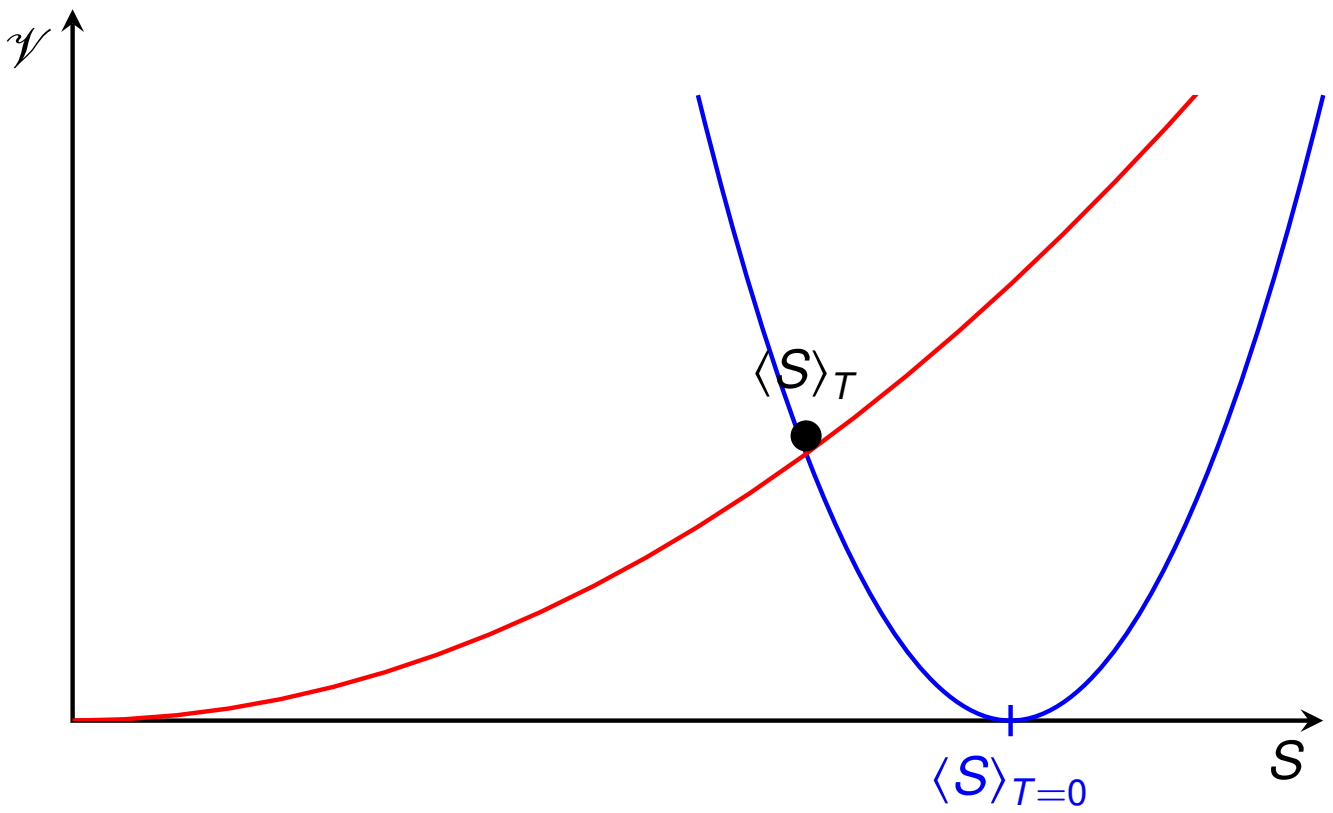

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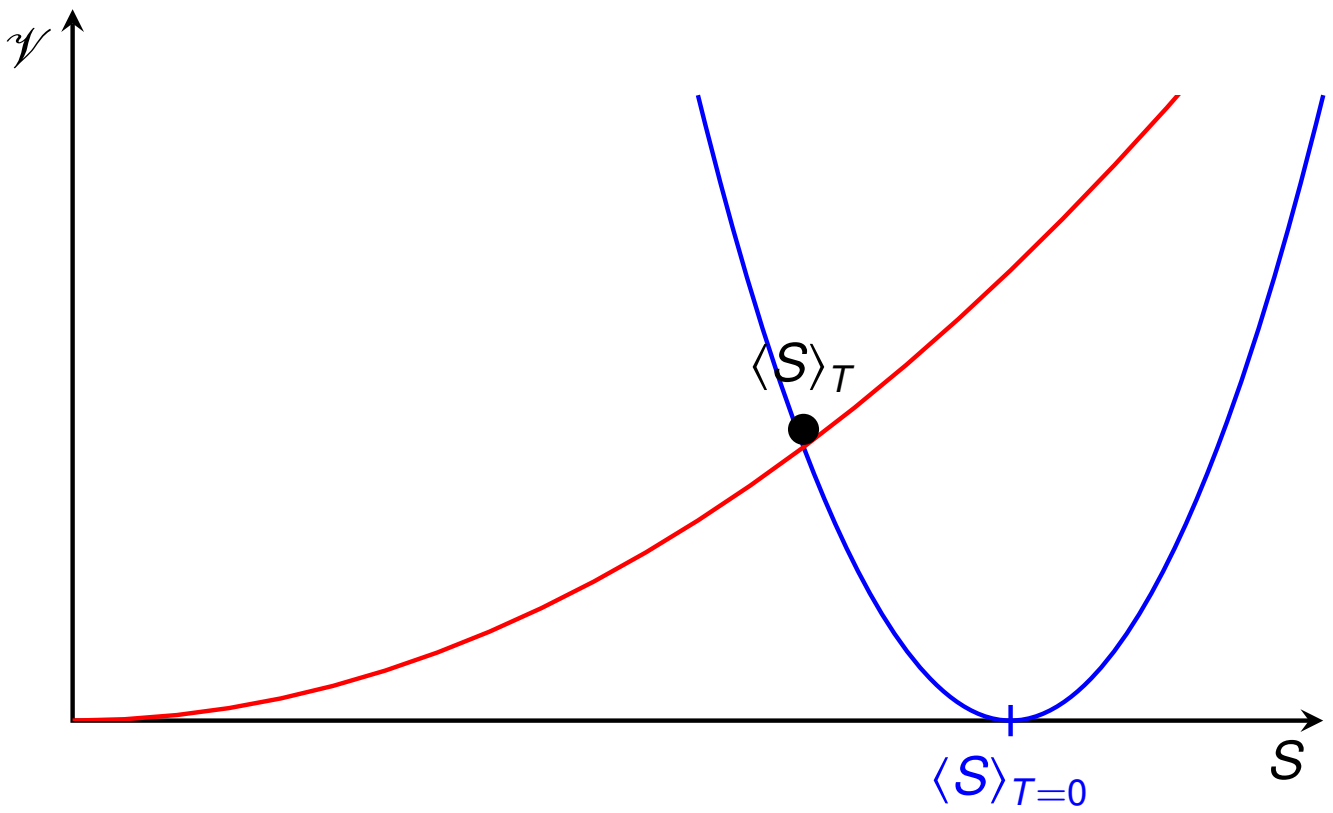

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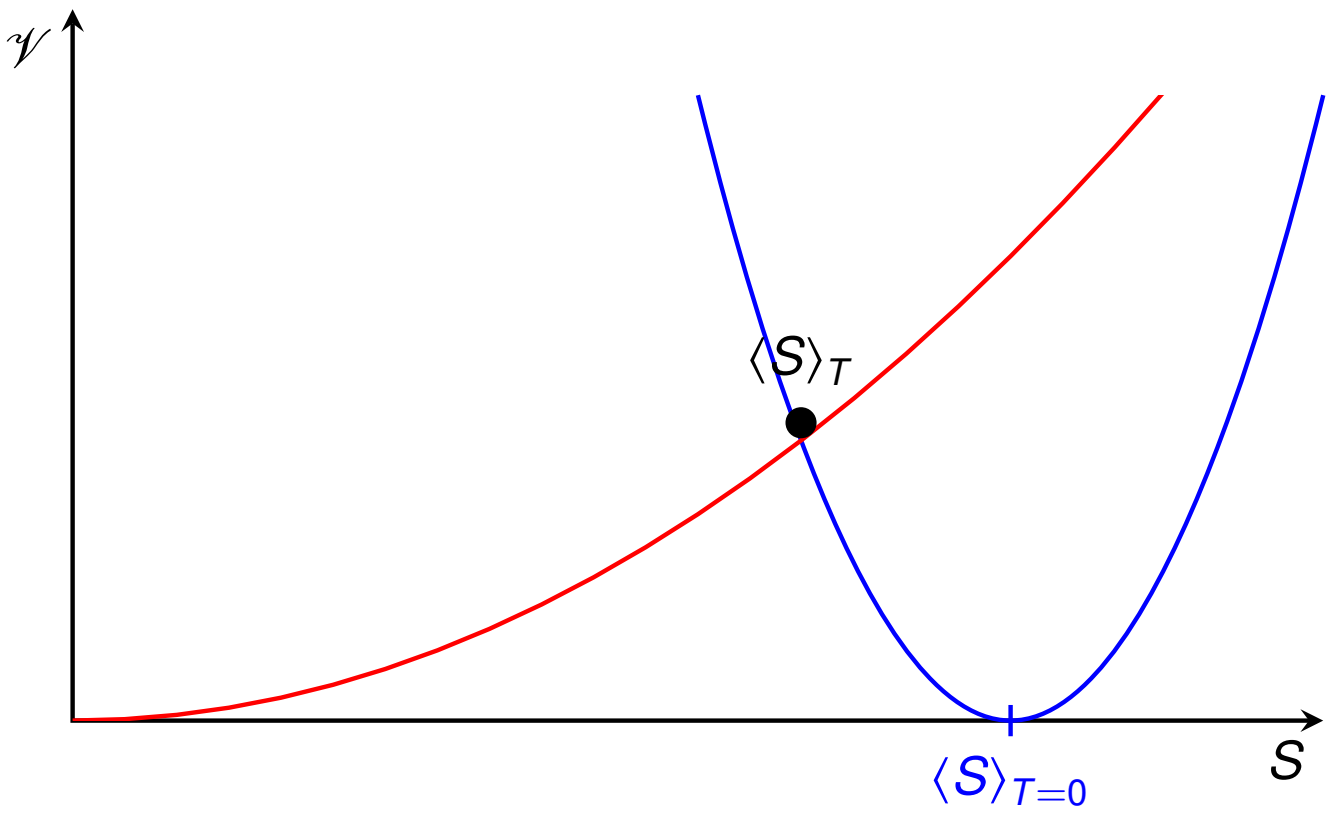

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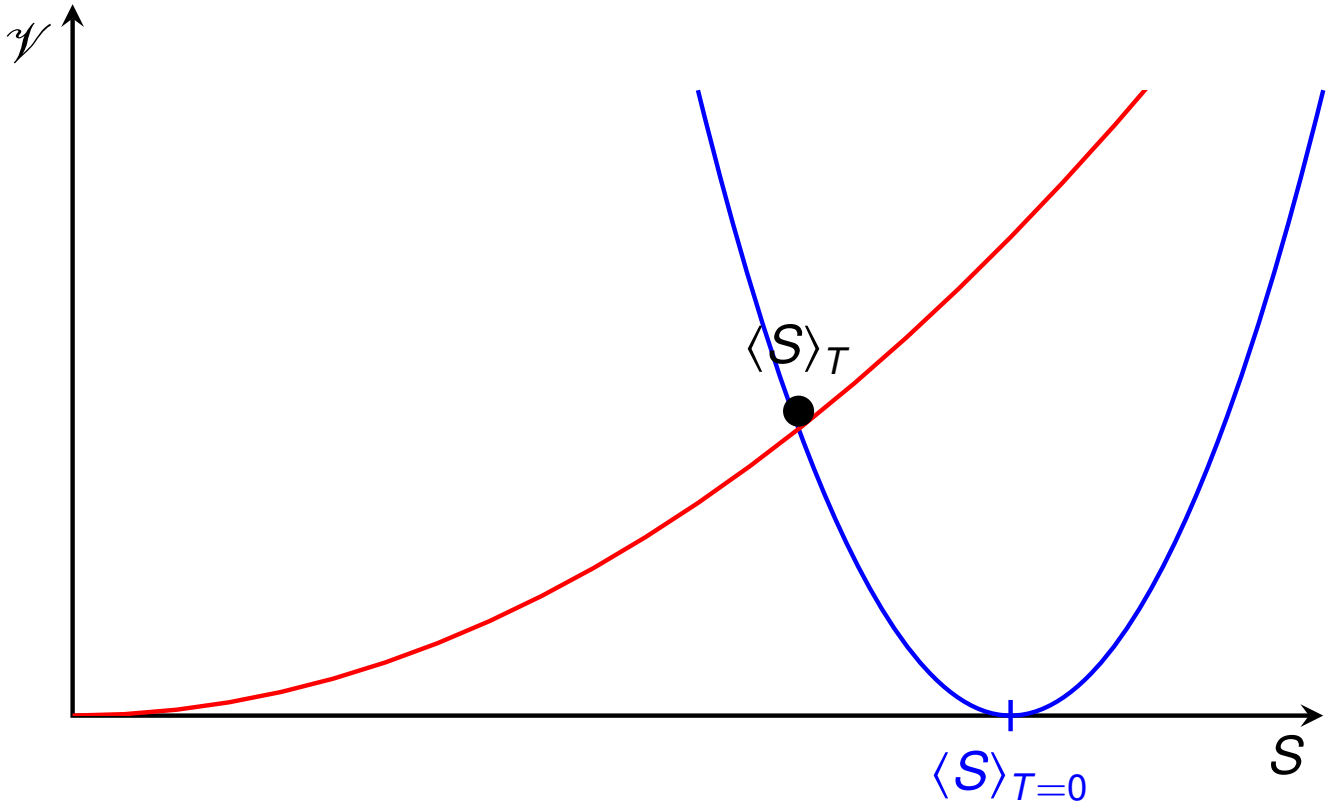

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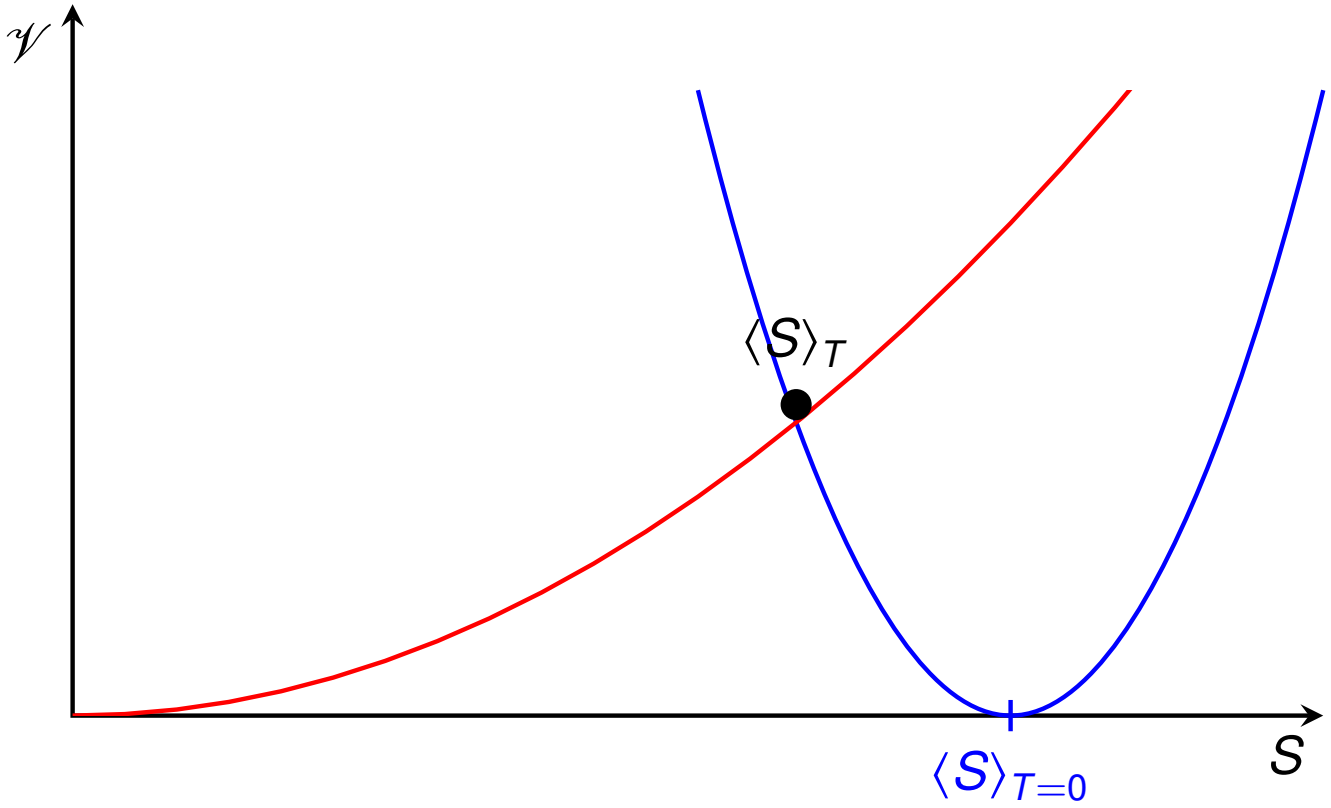

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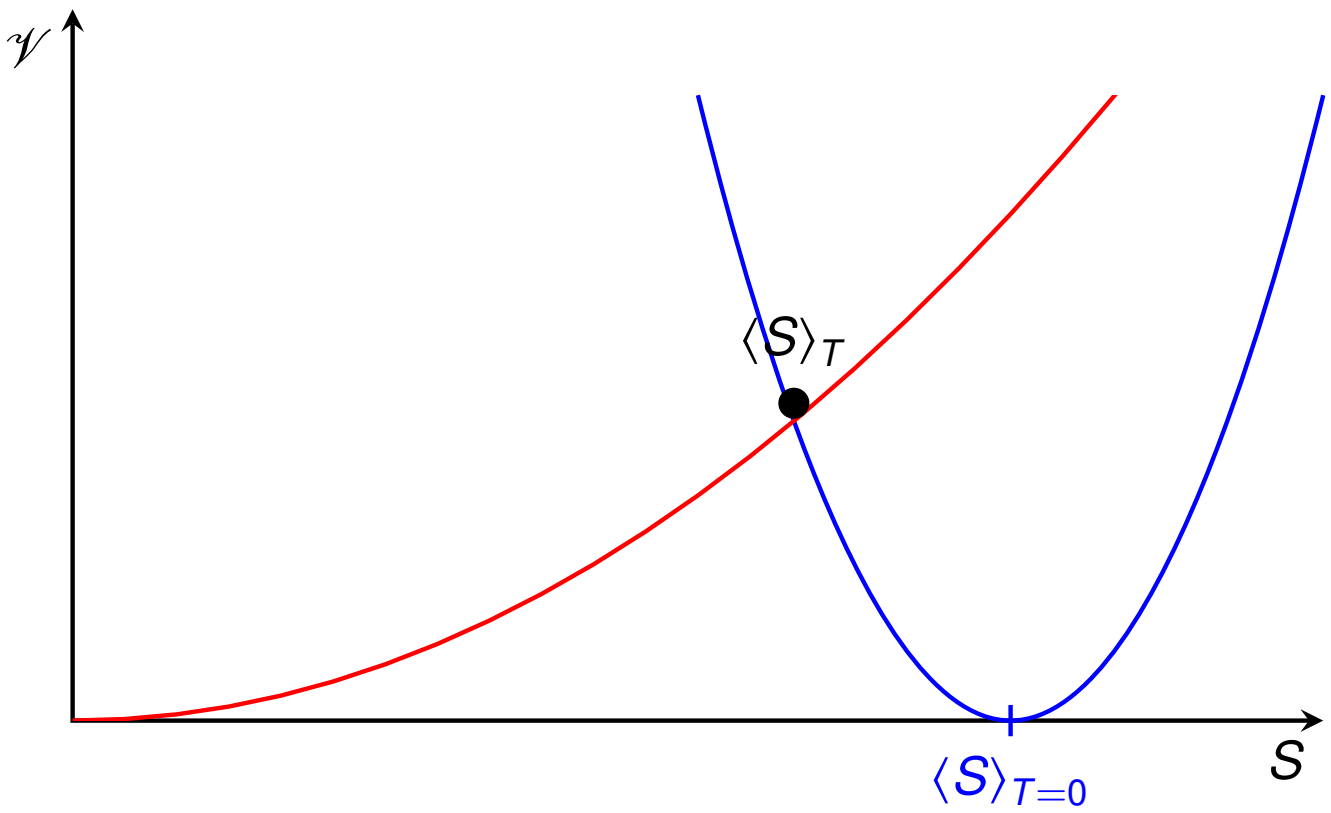

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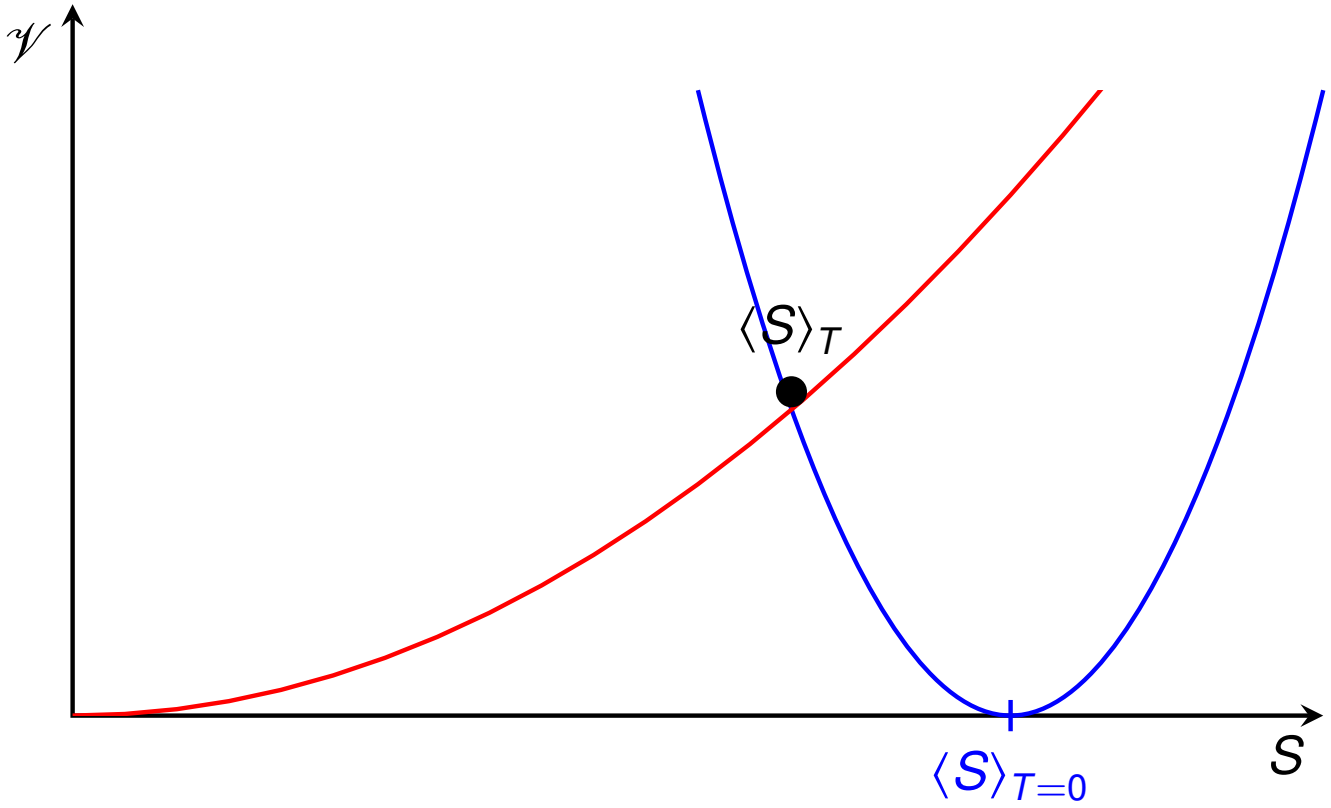

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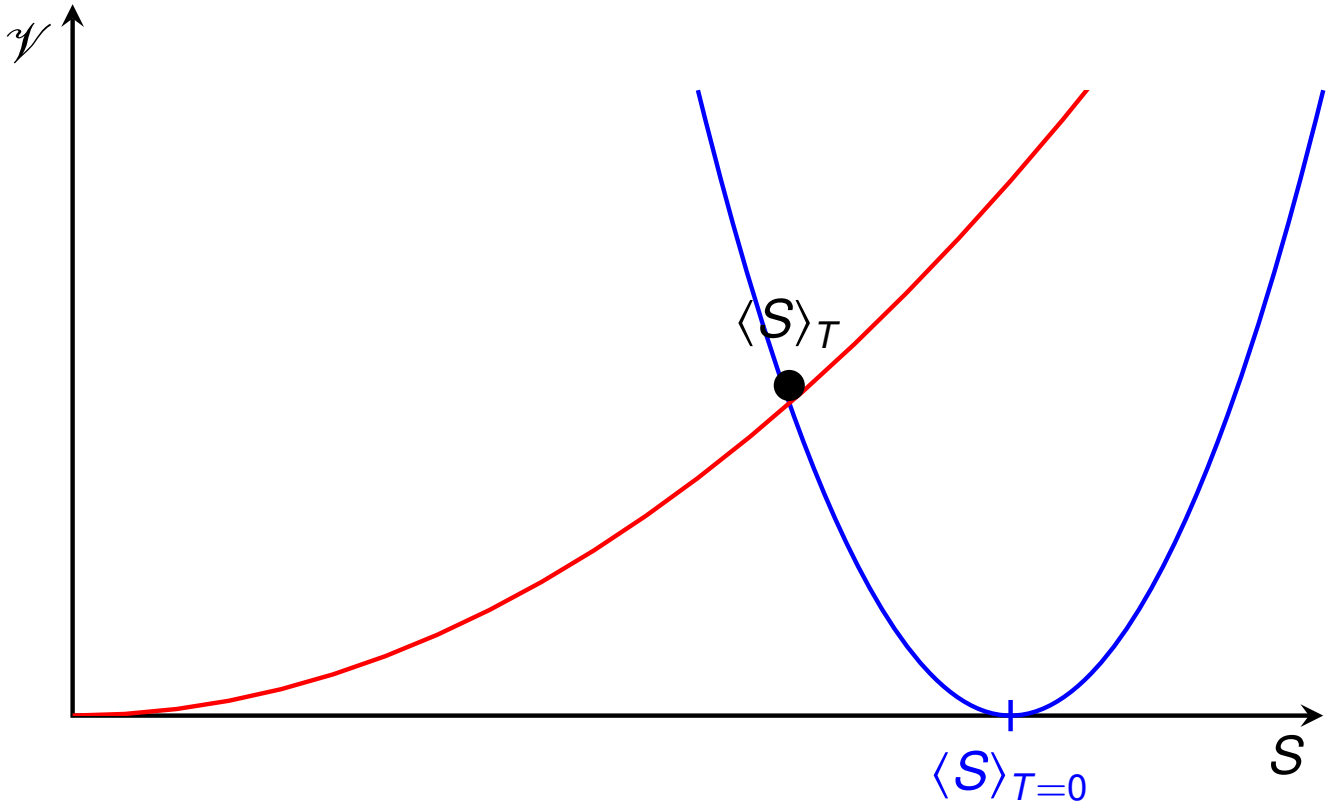

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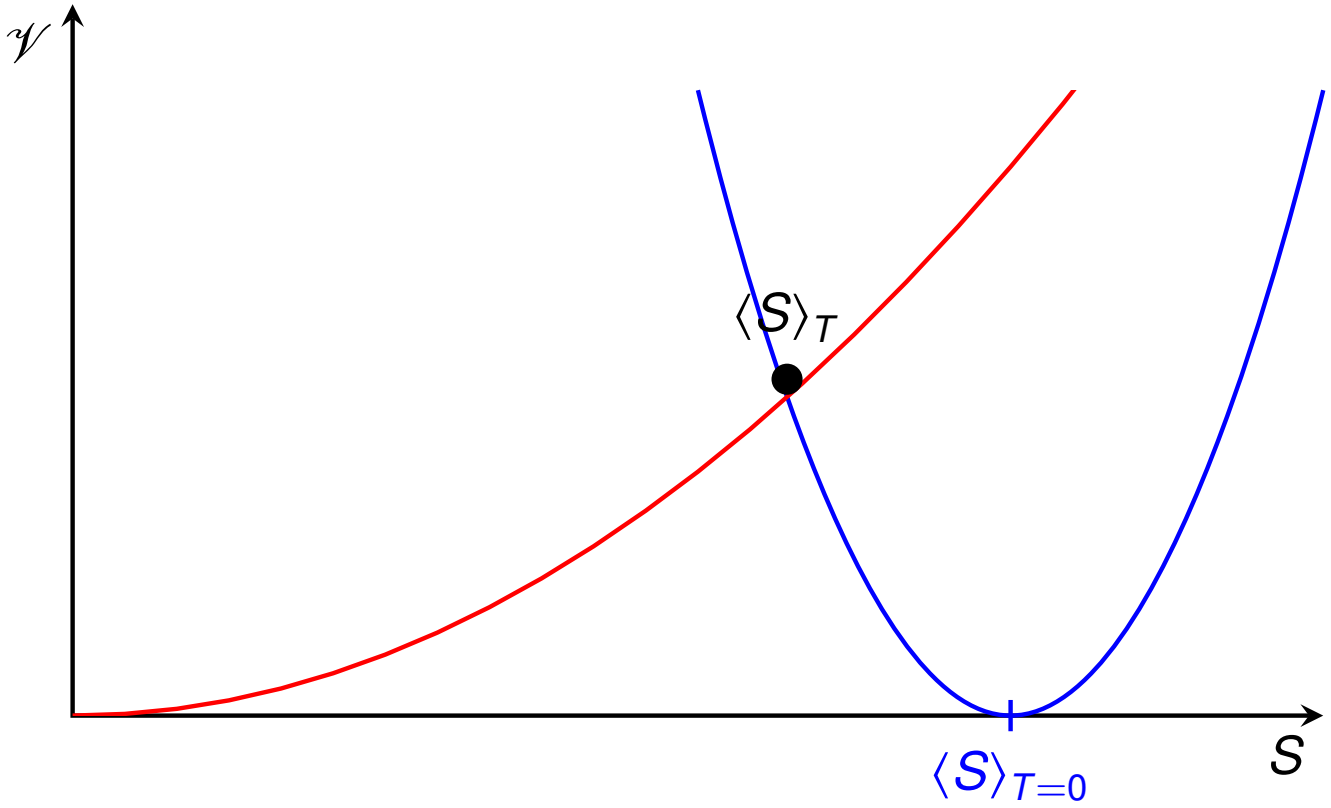

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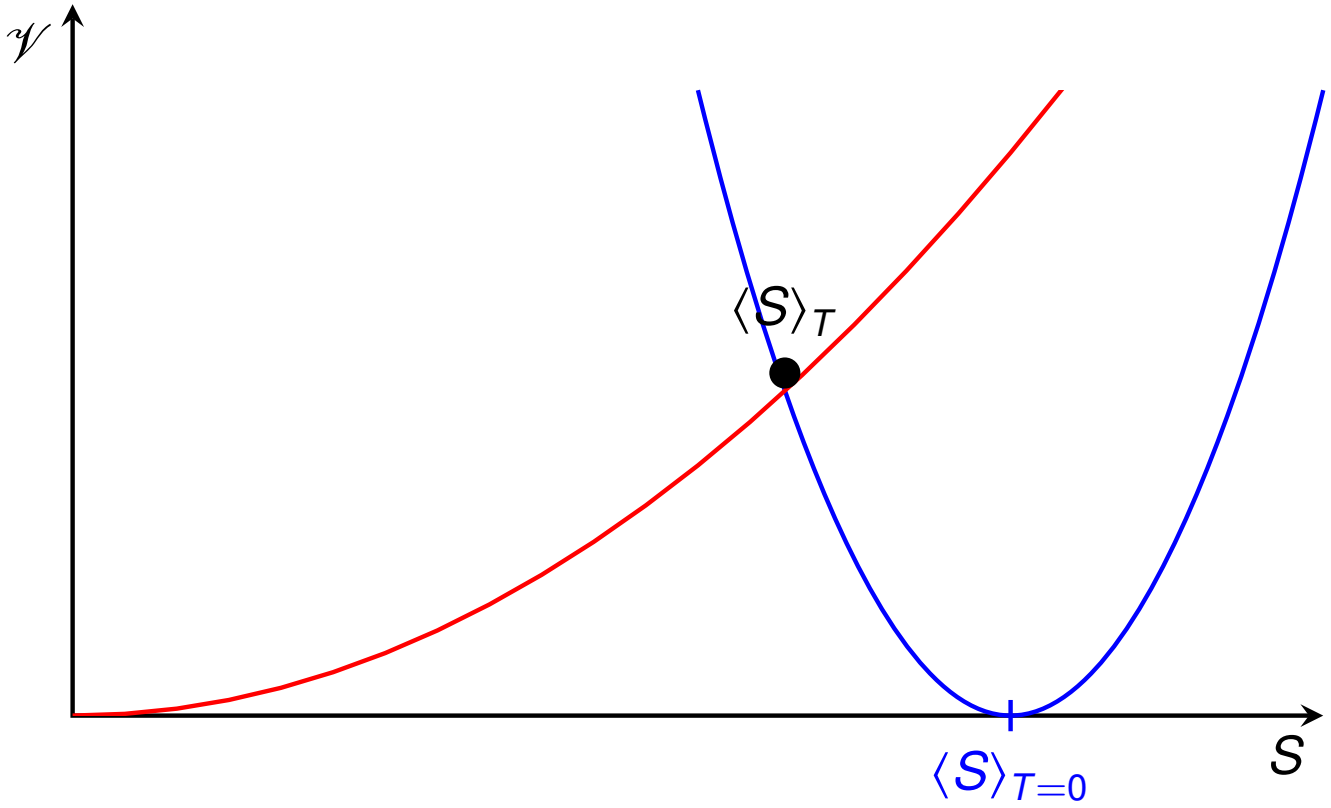

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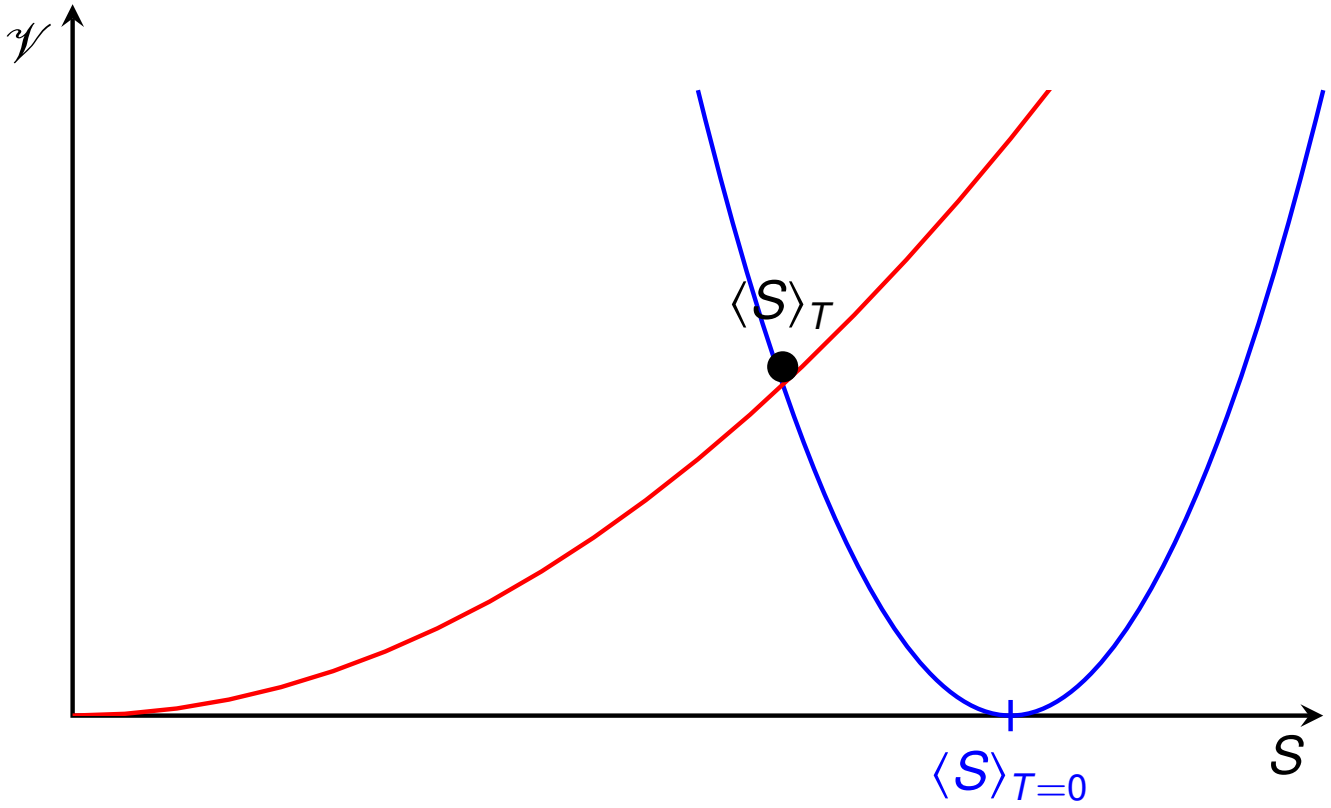

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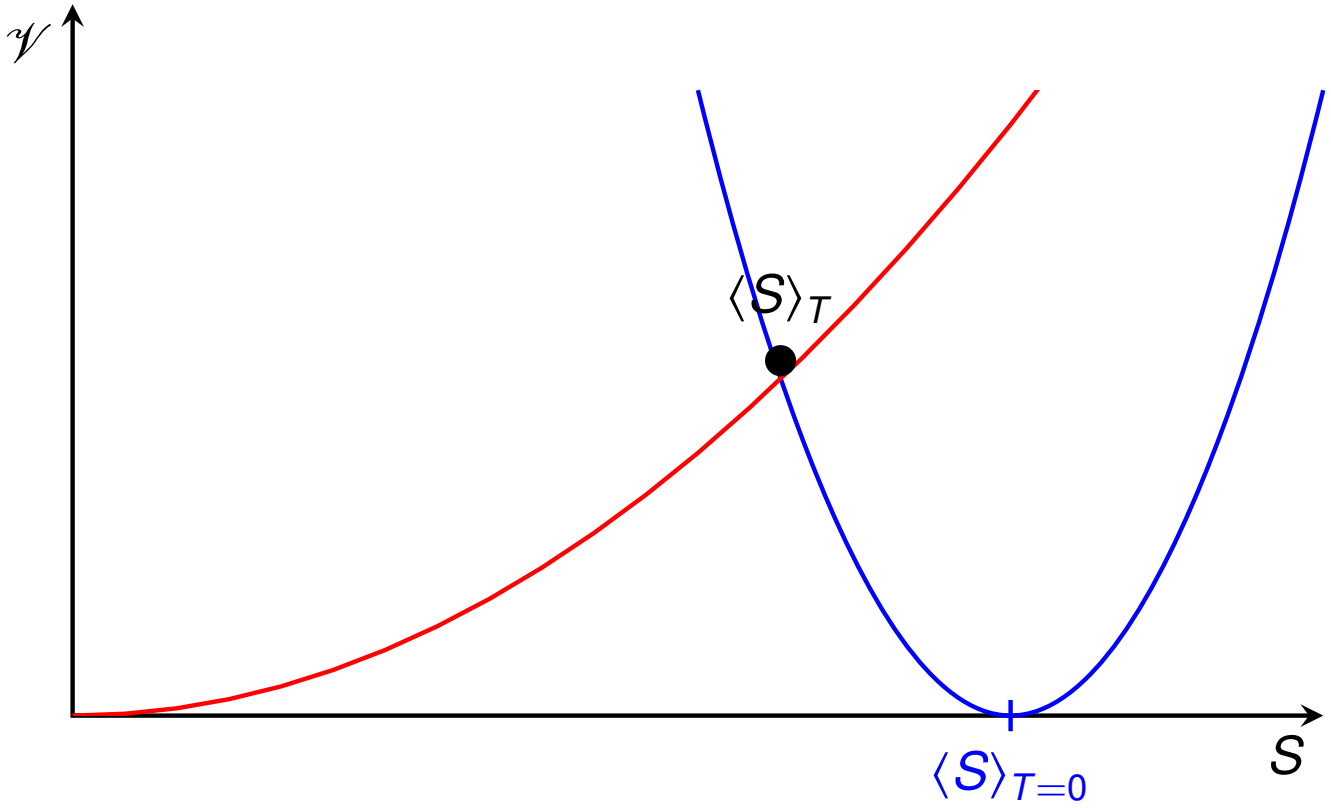

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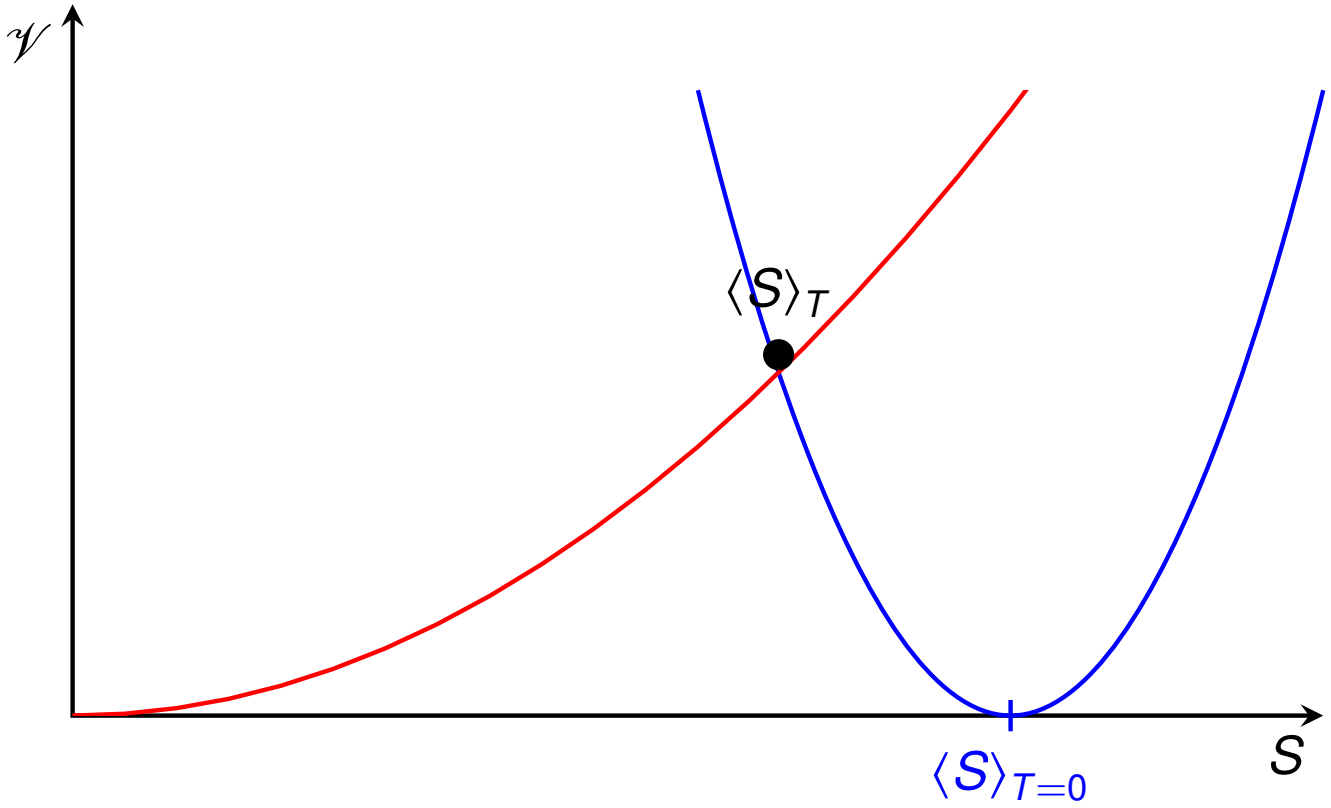

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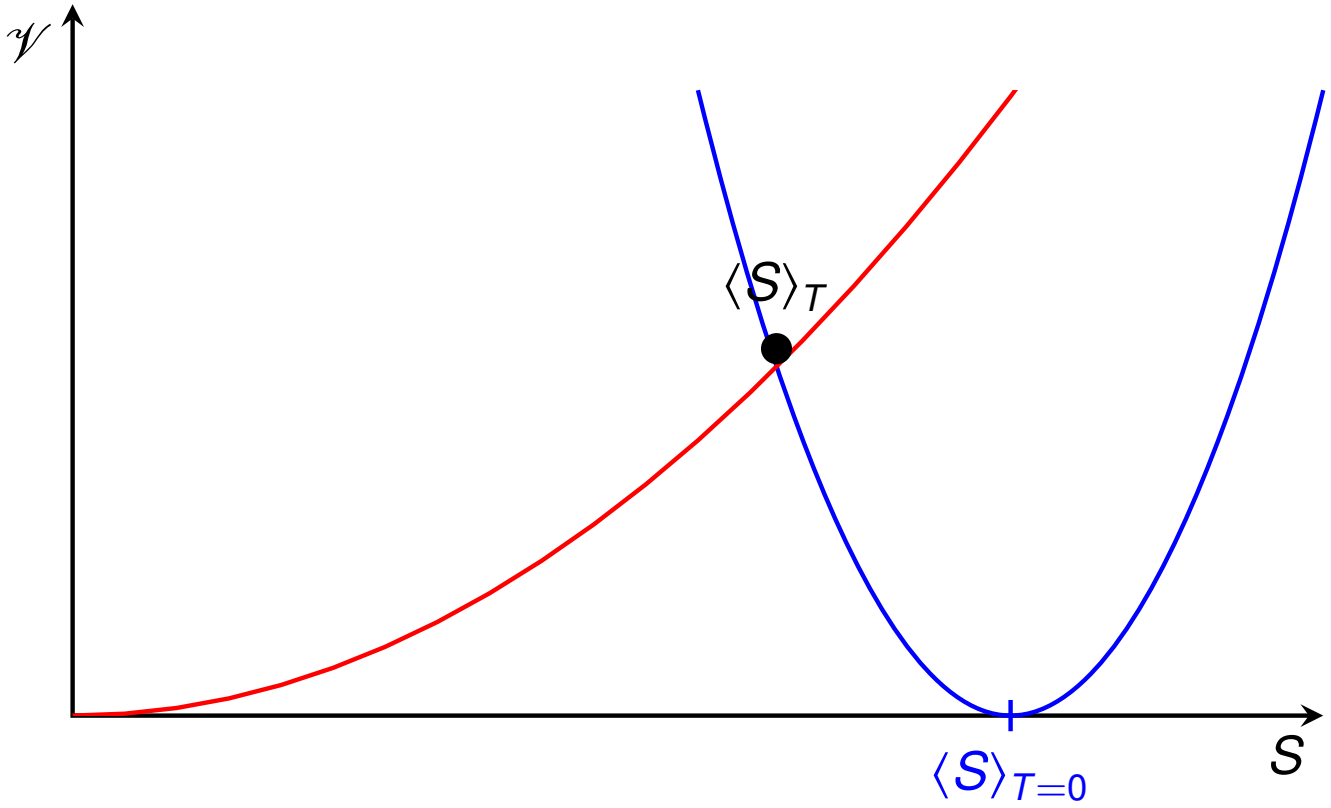

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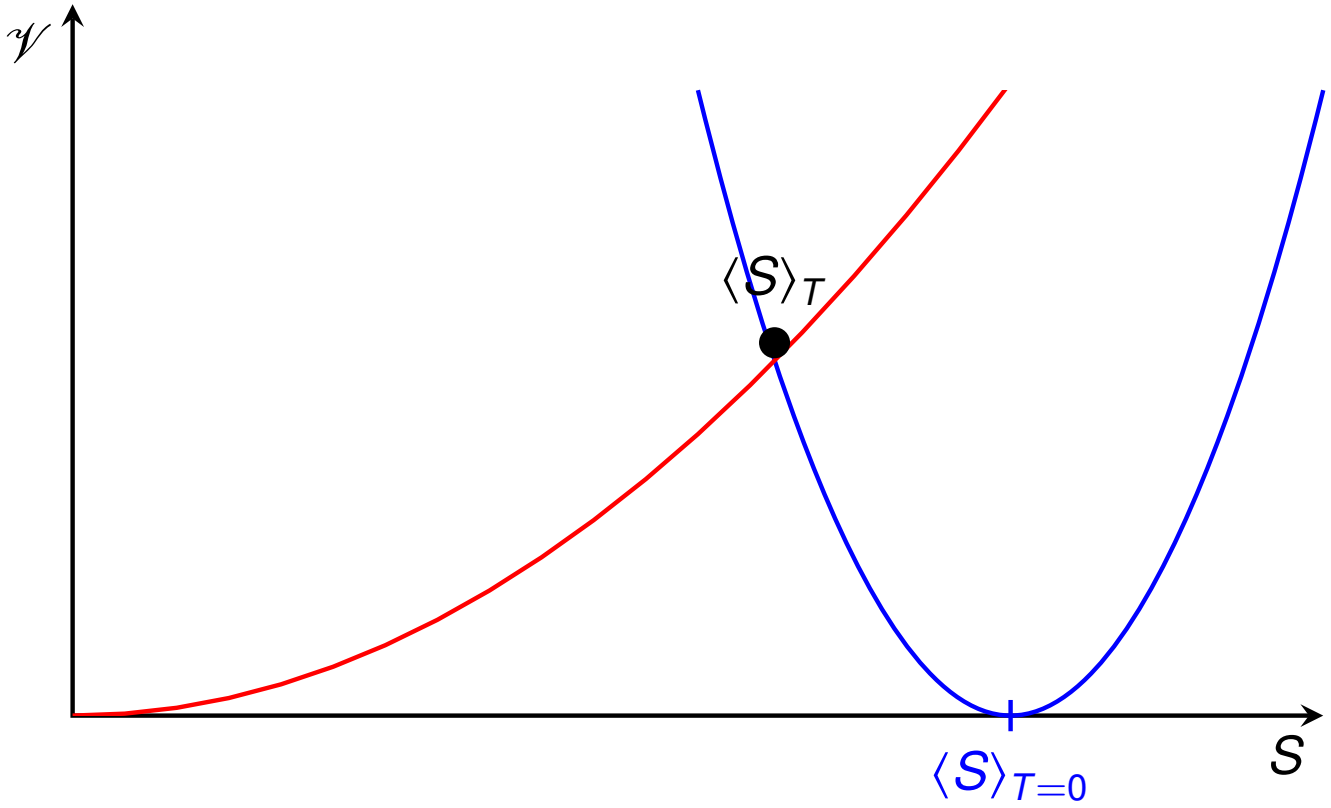

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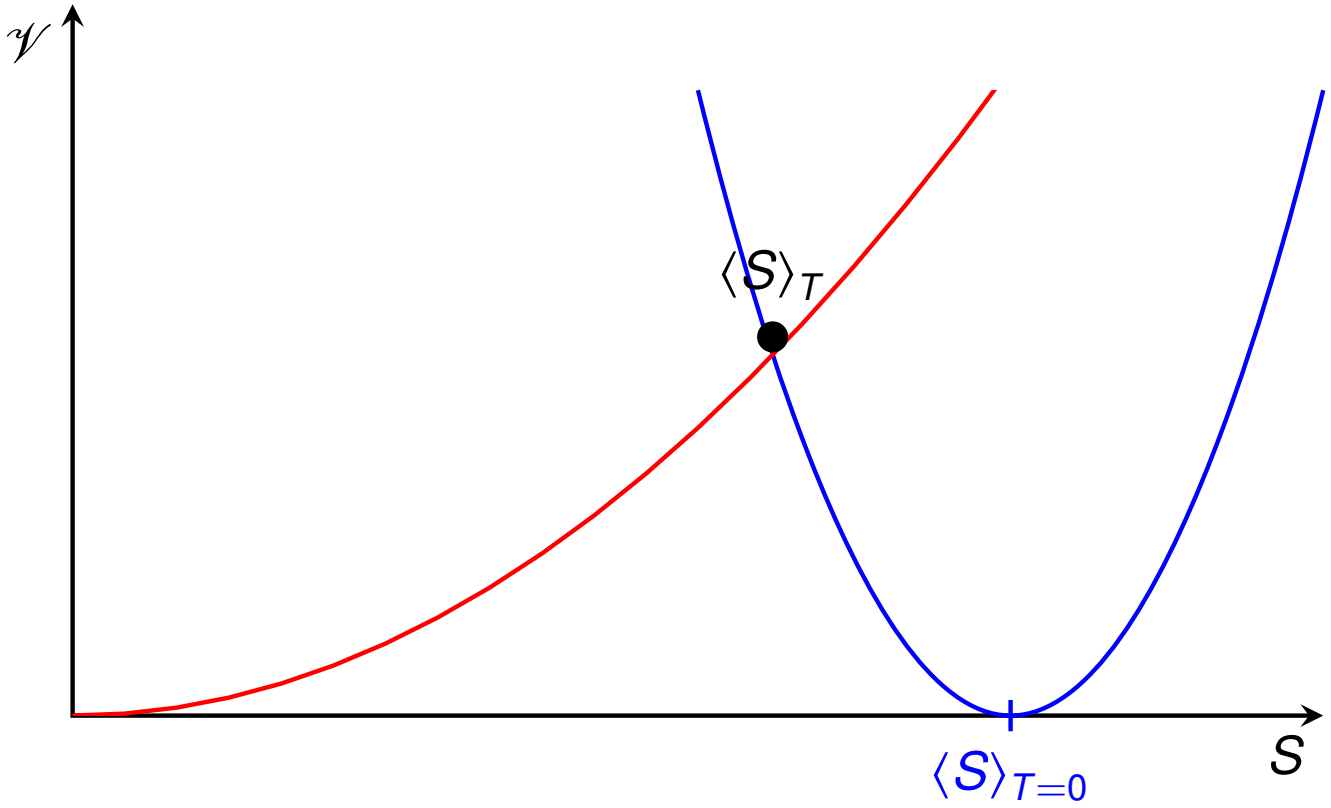

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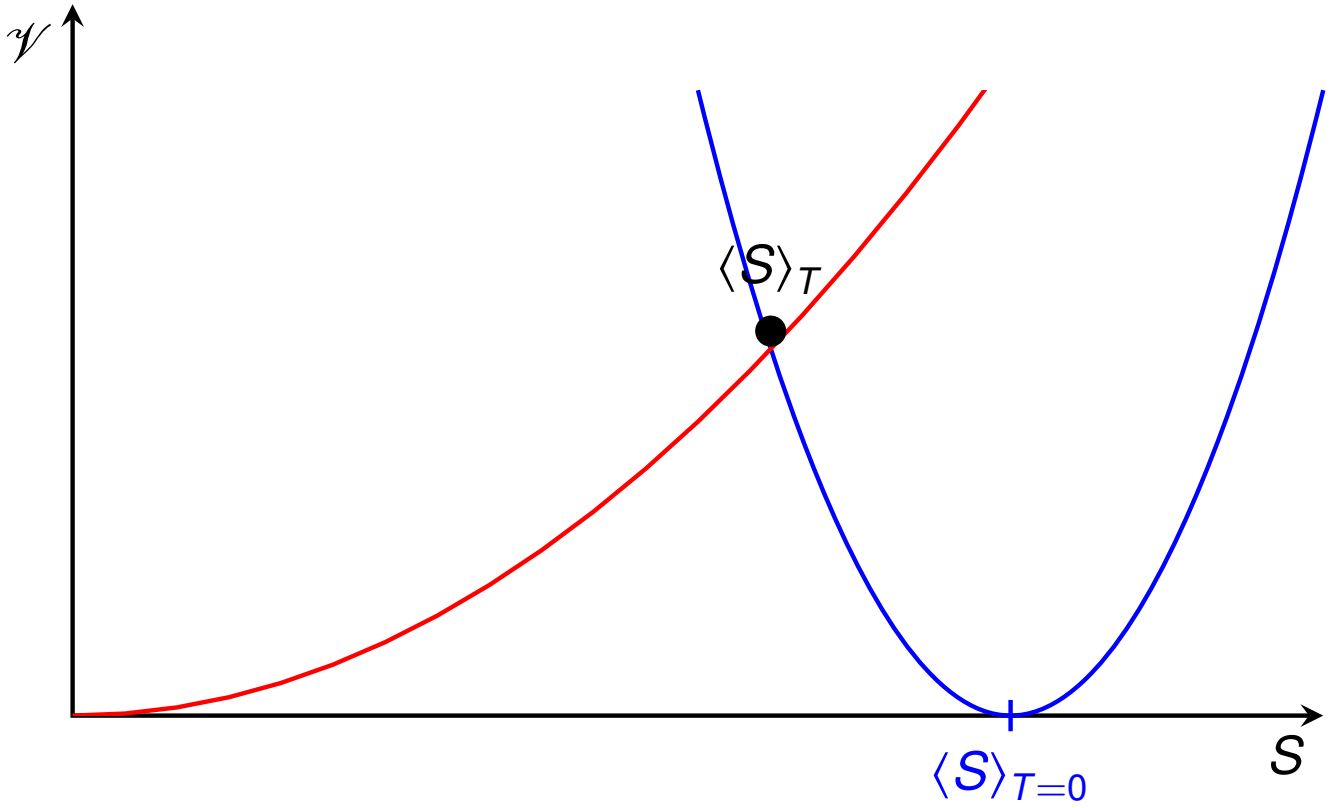

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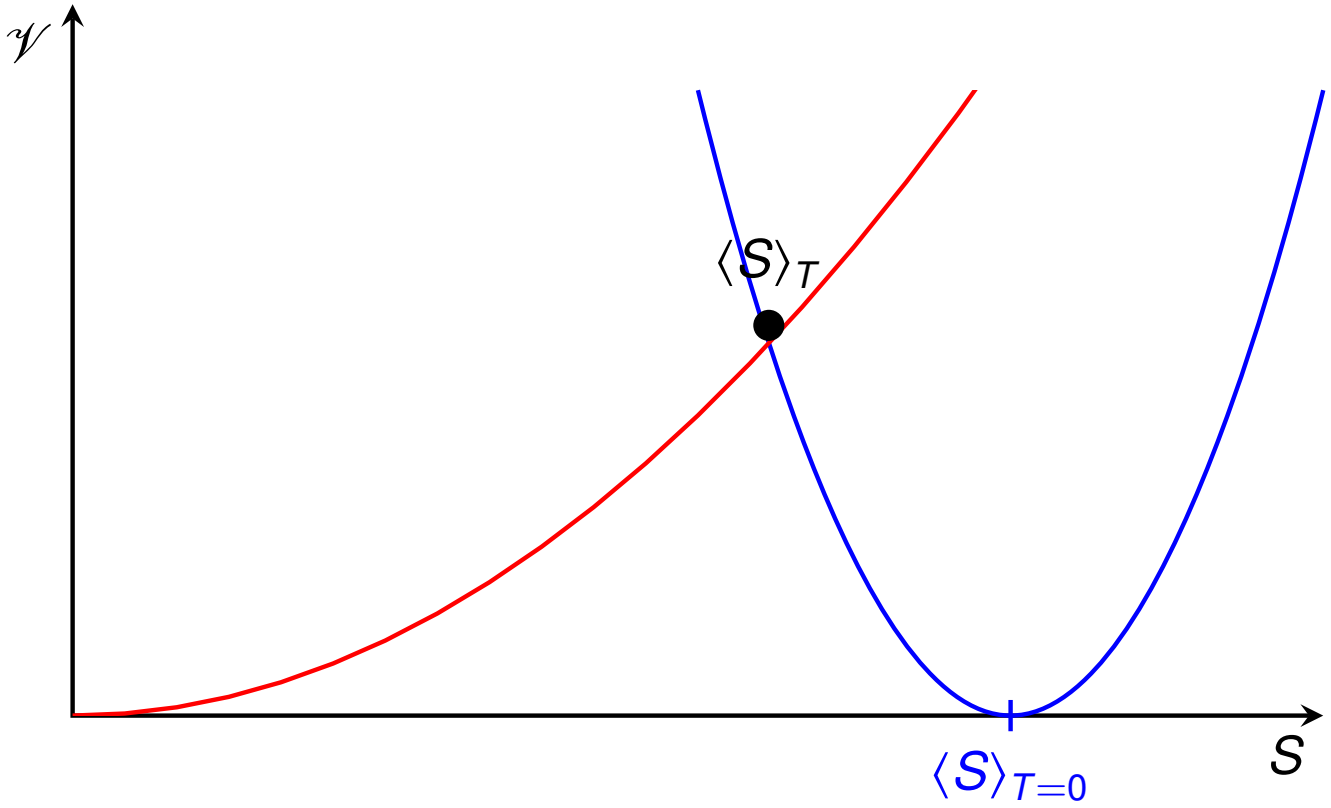

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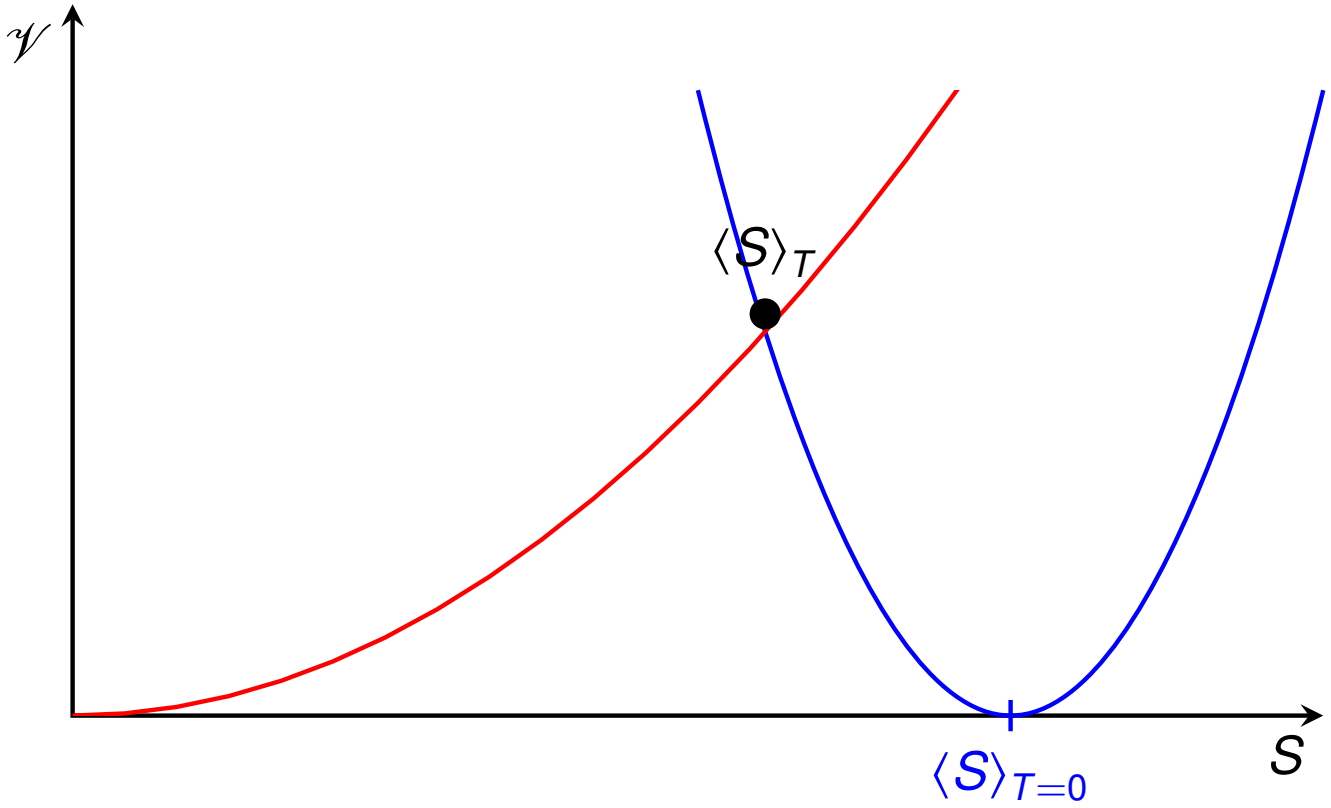
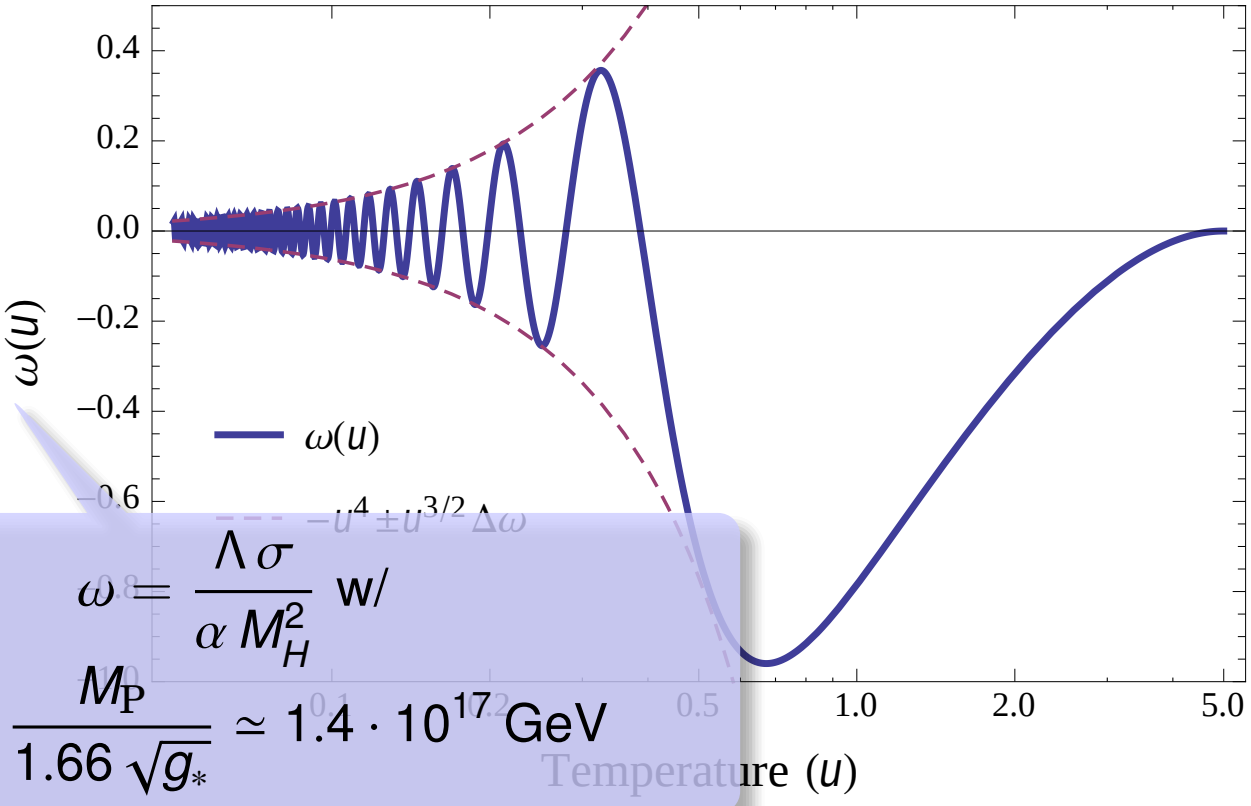


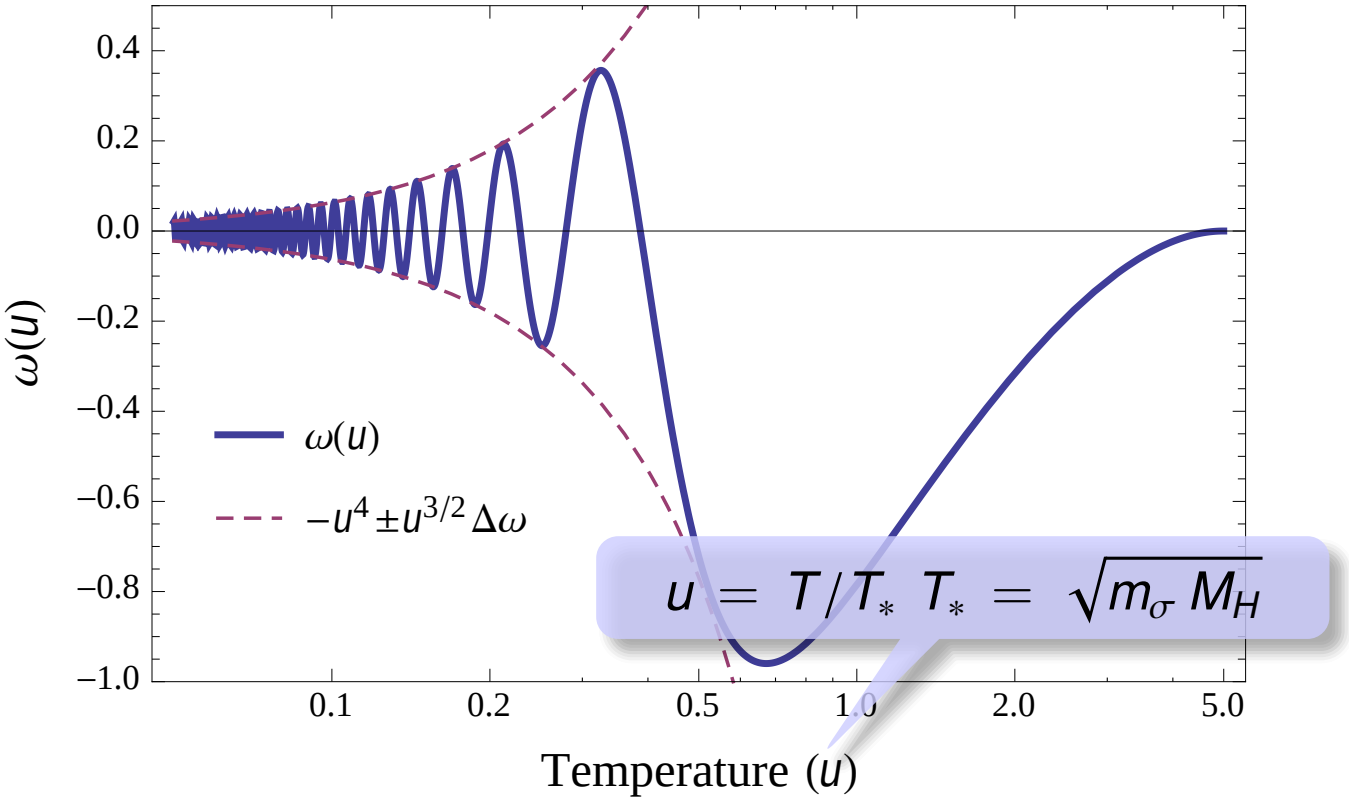
Flavon oscillations



$$\omega = \frac{\Lambda\,\sigma}{\alpha\, M_H^2} \quad \text{w/}$$

$$M_H = \frac{M_{\rm P}}{1.66\,\sqrt{g_*}} \simeq 1.4 \cdot 10^{17}\,\text{GeV}$$

Flavon oscillations



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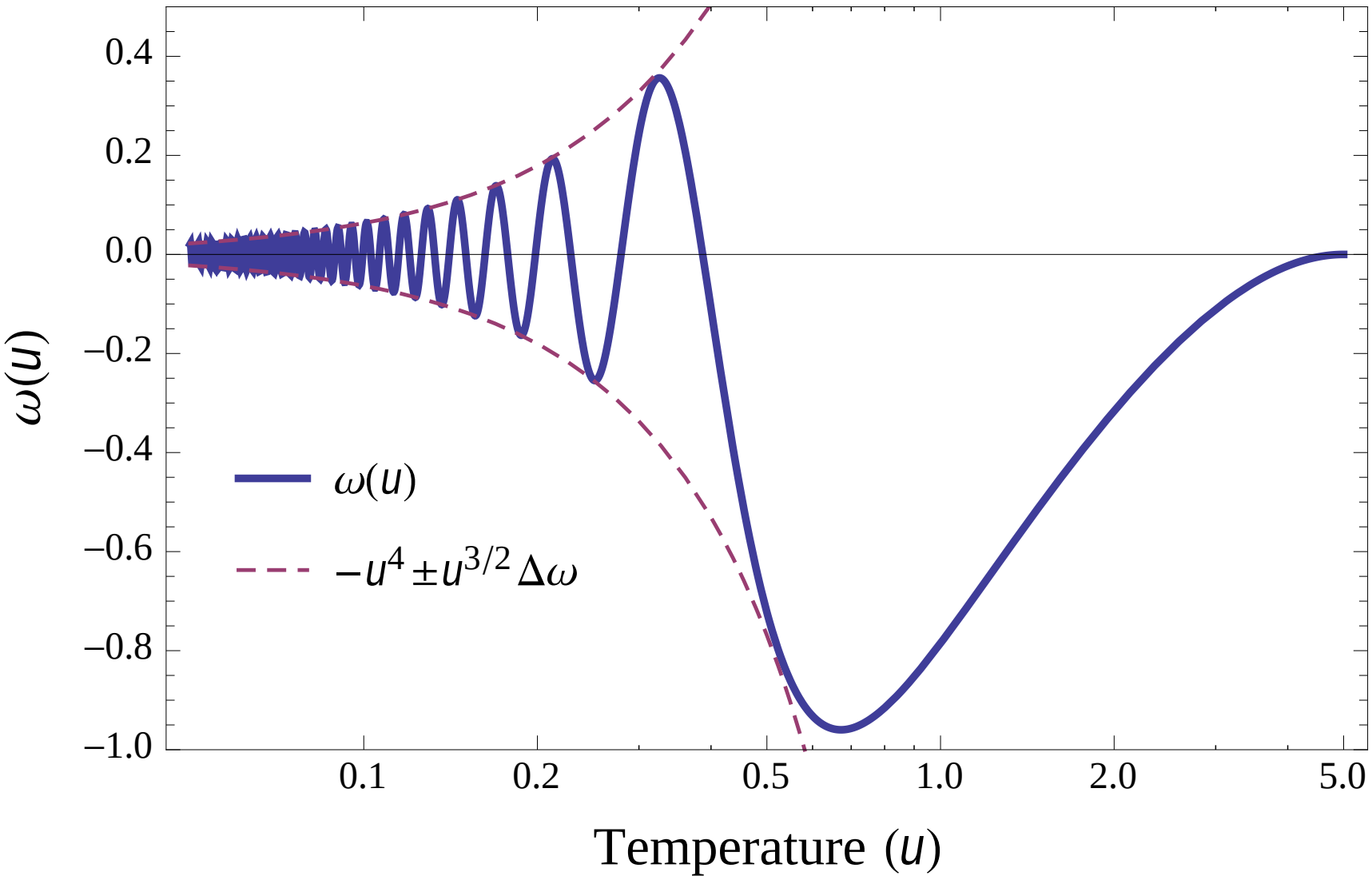

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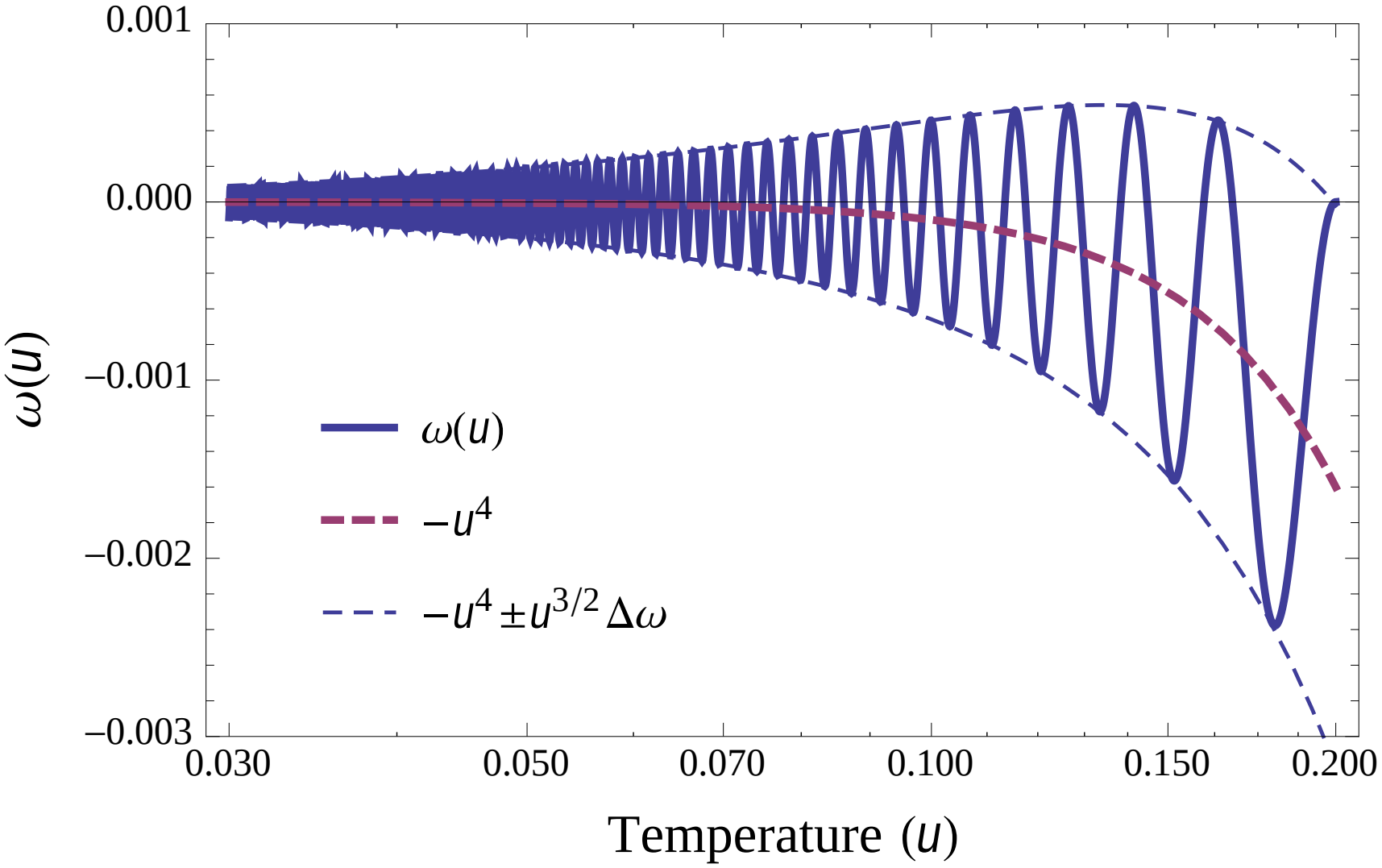
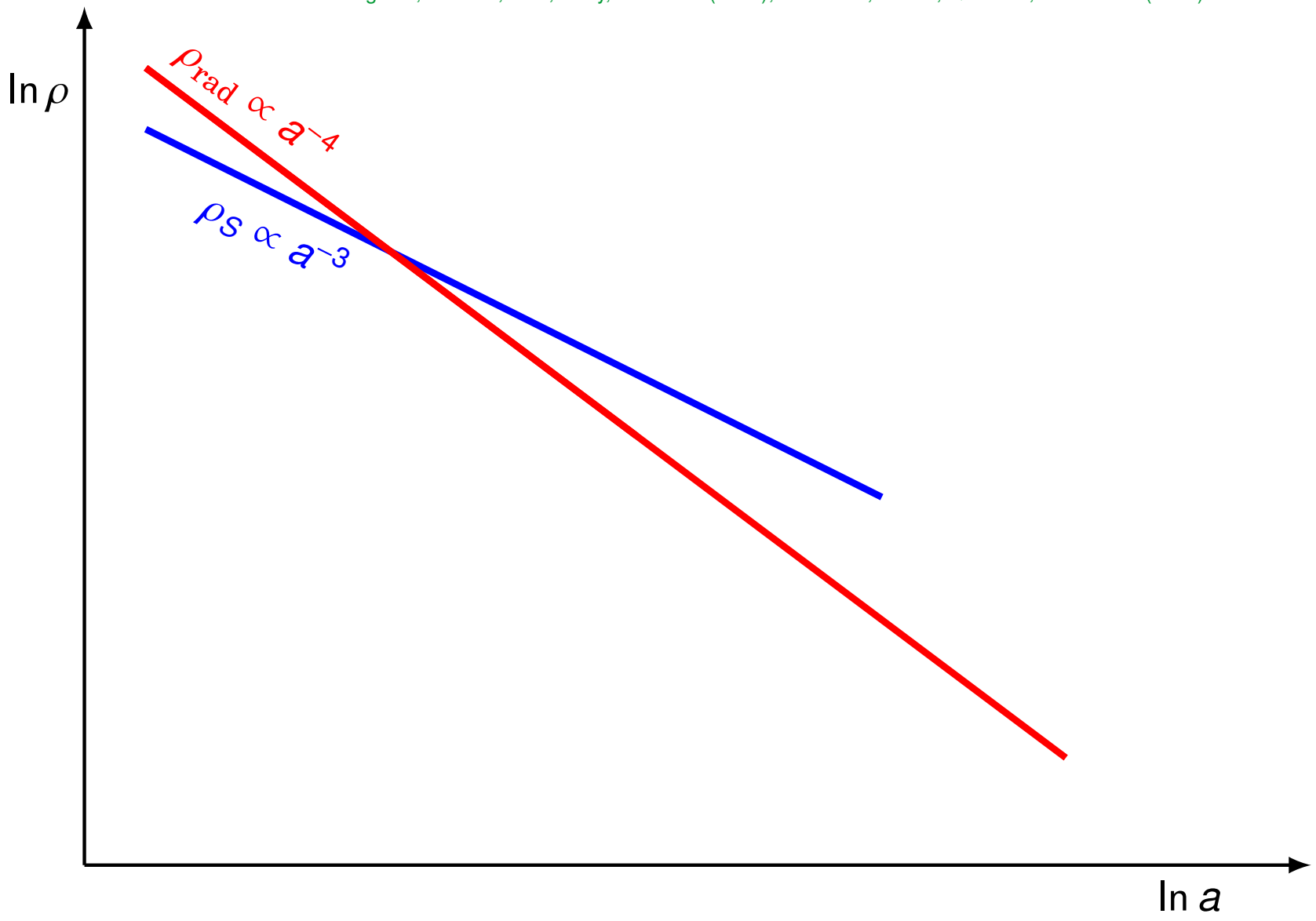


Moduli problems

Coughlan, Fischler, Kolb, Raby, and Ross (1983); de Carlos, Casas, Quevedo, and Roulet (1993)



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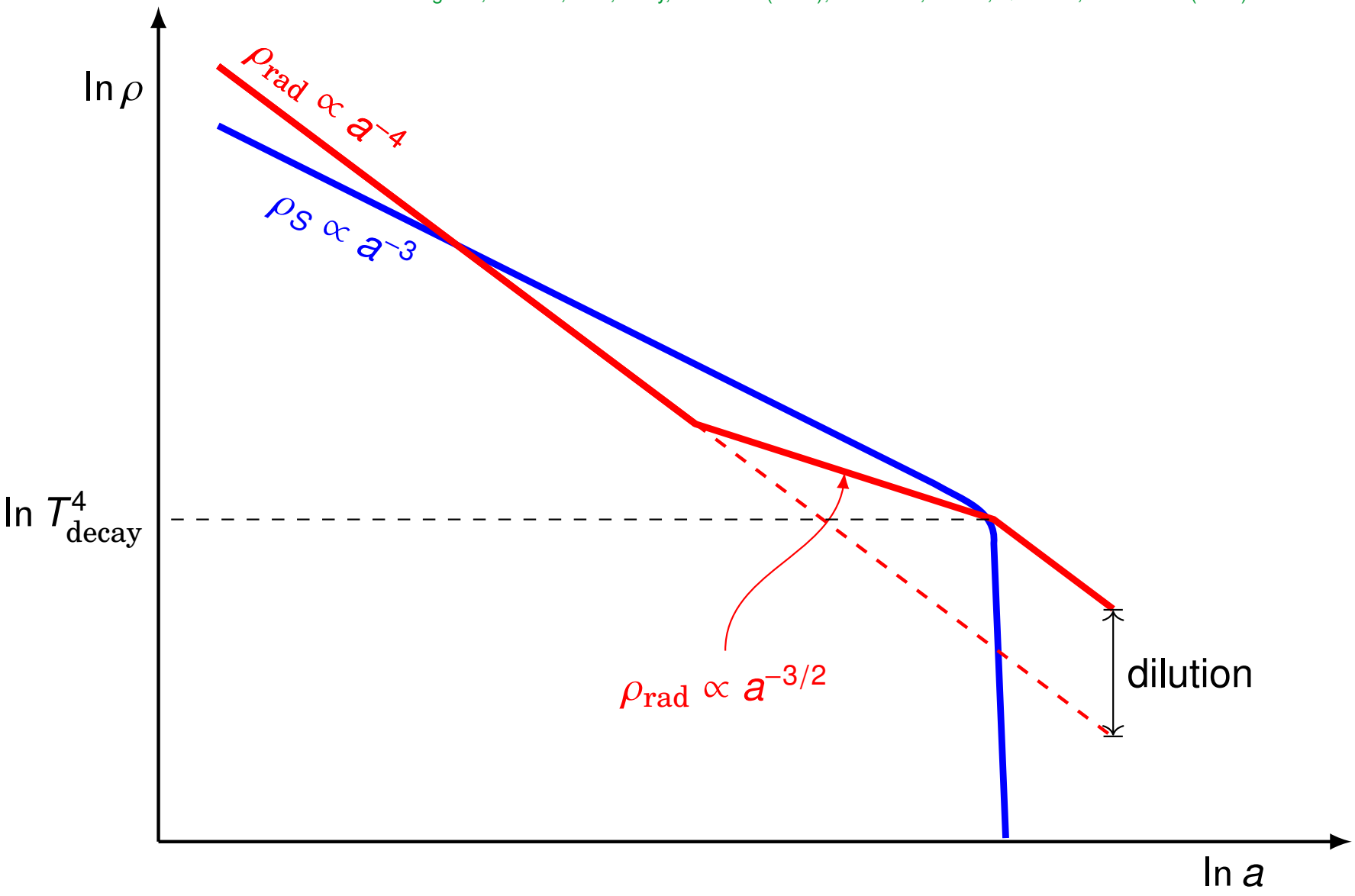

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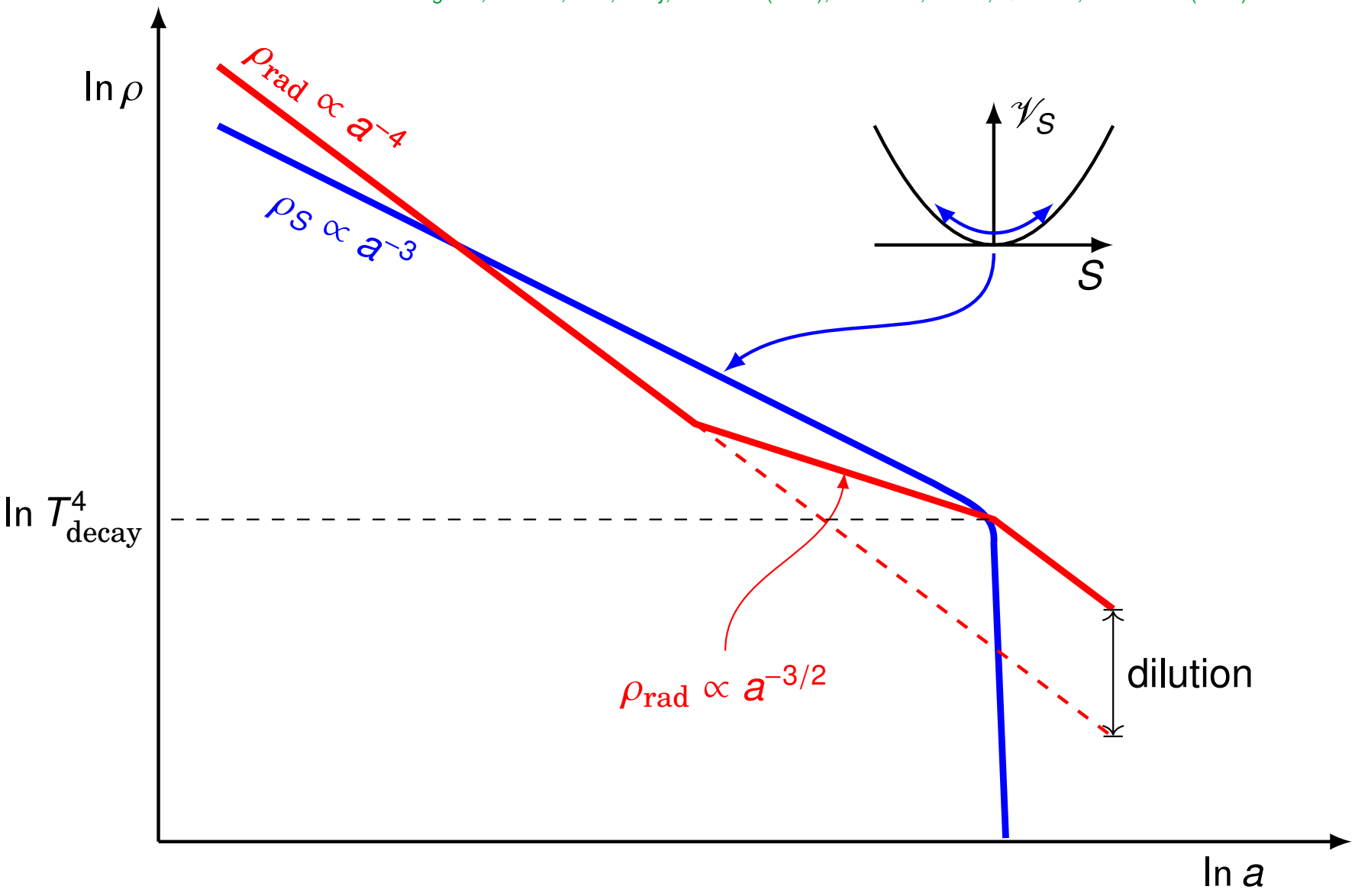

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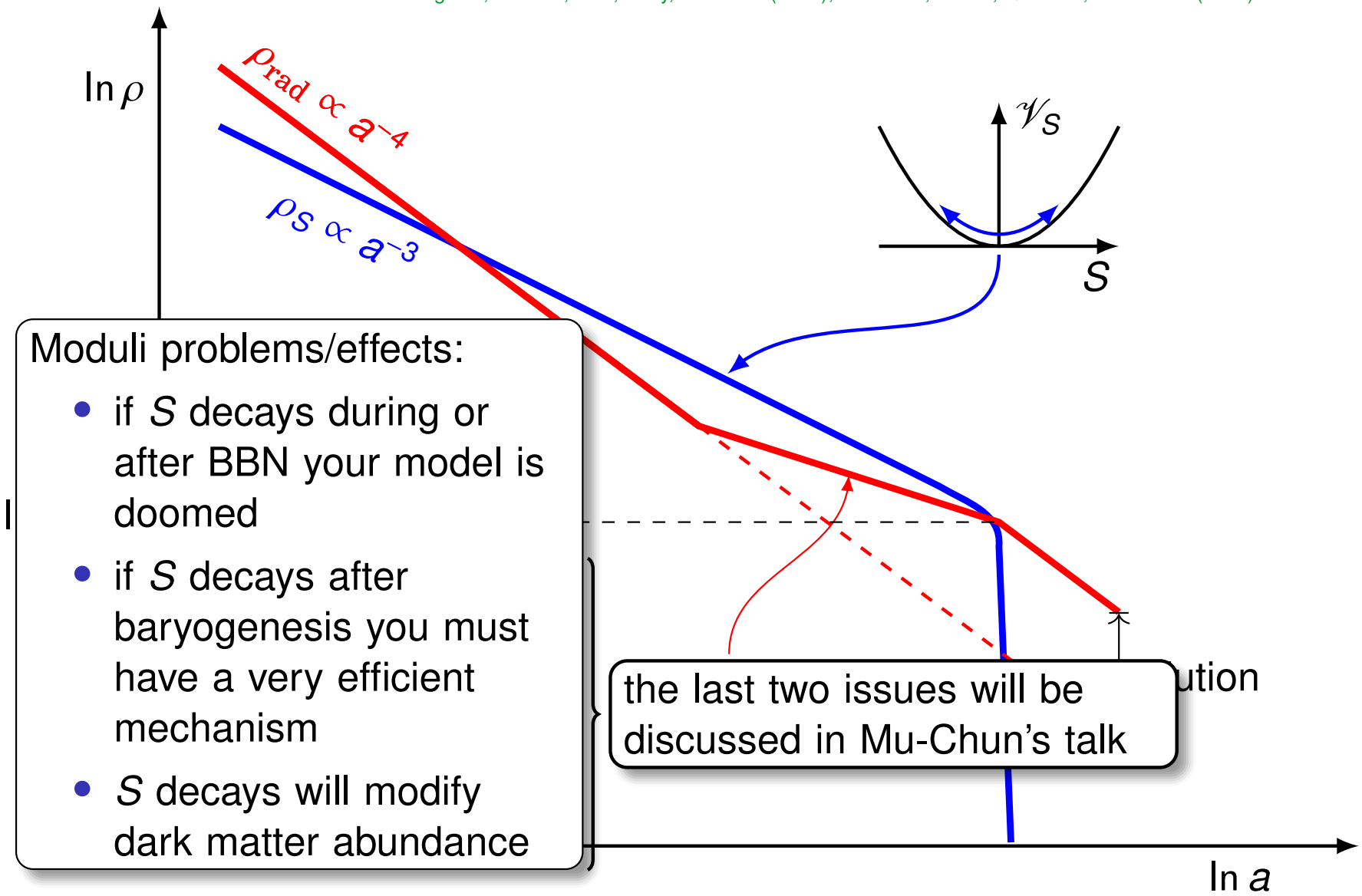
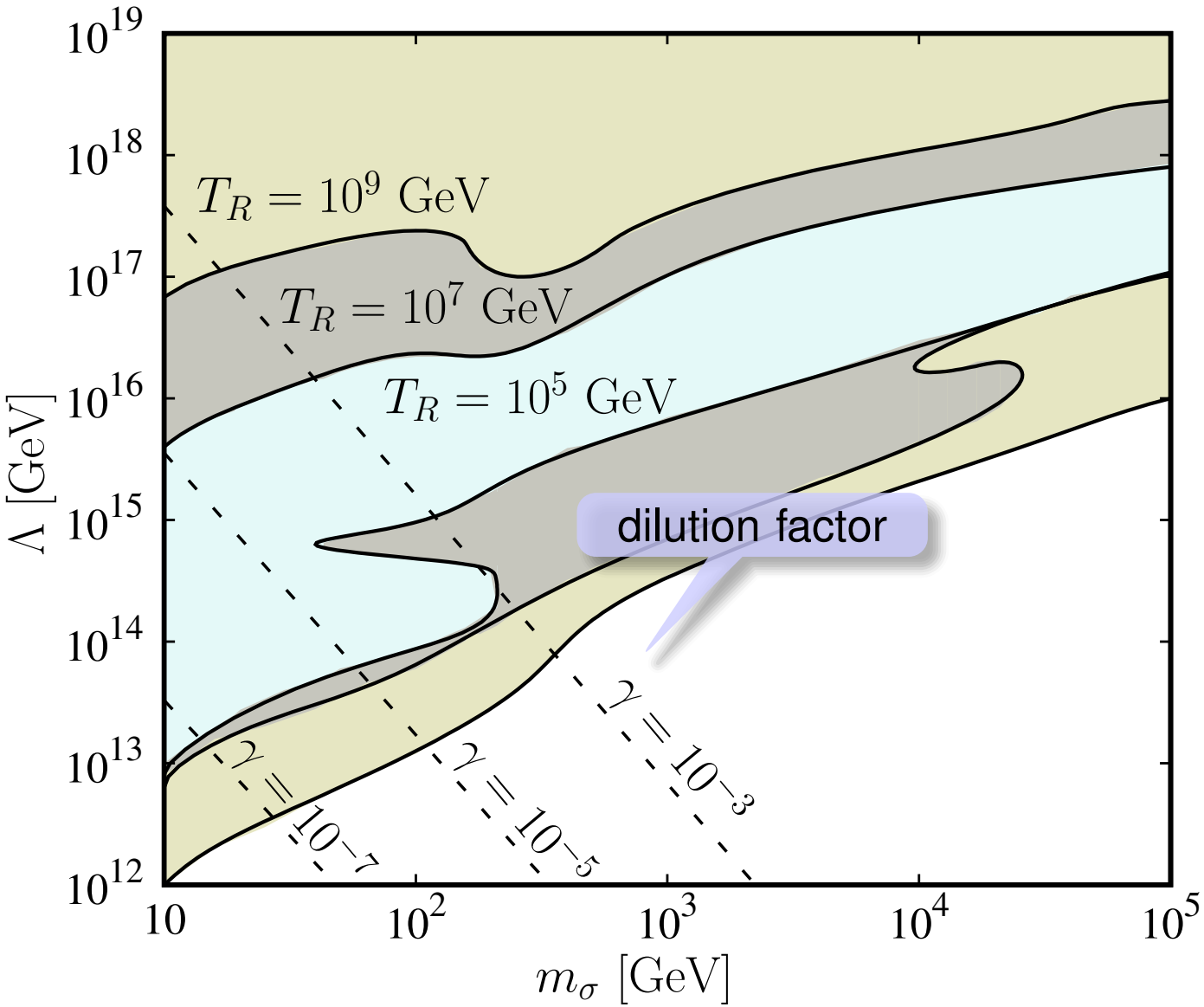


Moduli problems/effects:

- if S decays during or after BBN your model is doomed
- if S decays after baryogenesis you must have a very efficient mechanism
- S decays will modify dark matter abundance

the last two issues will be discussed in Mu-Chun's talk

BBN constraints



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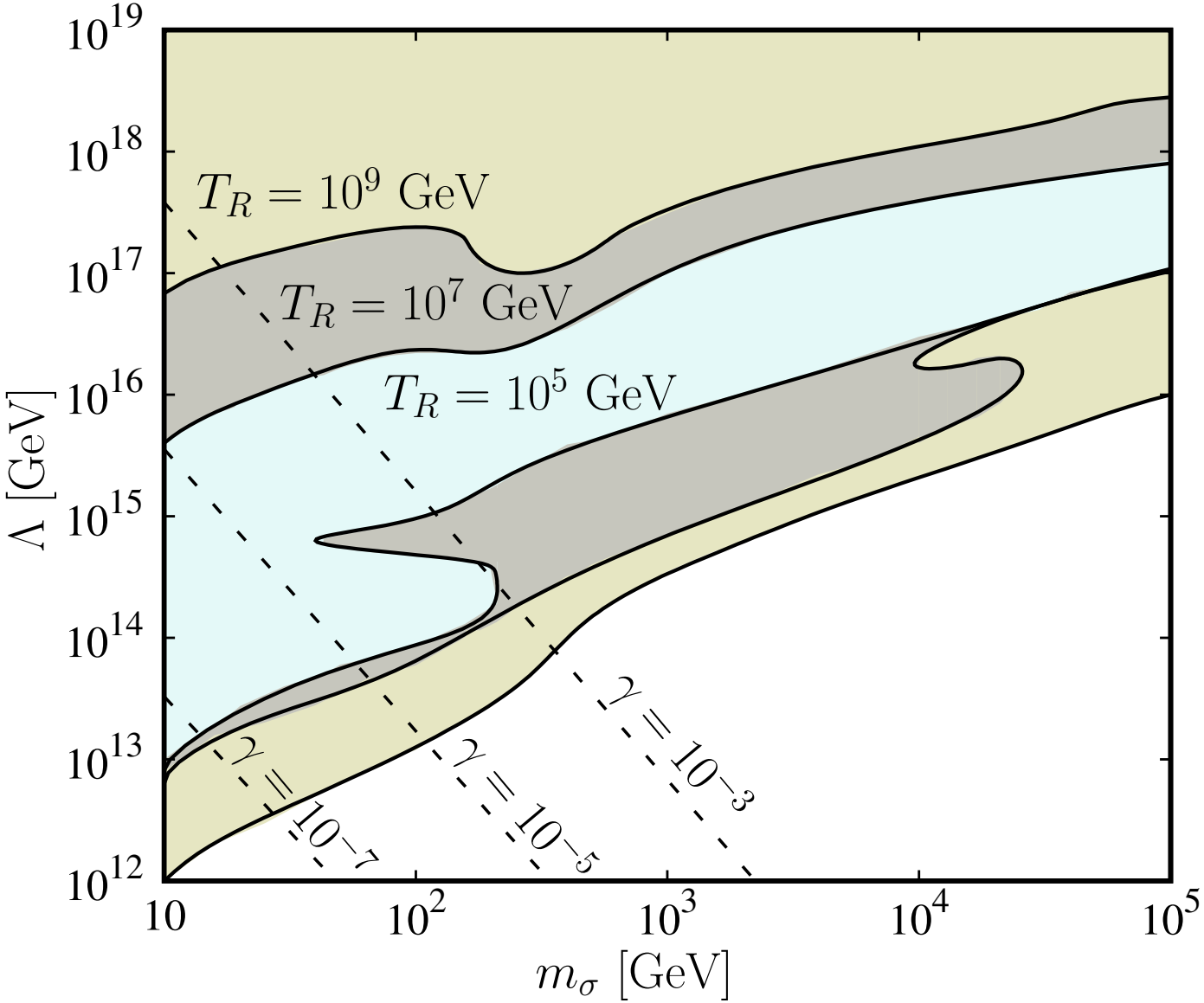

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bottom–line:

moduli problems more severe than generally appreciated

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$$\Delta\mathscr{V} \;=\; \mathcal{F}\Big(g(s), y(S)\Big)$$

- bound on reheating temperature in standard mechanisms of dilaton fixing: $T_R \lesssim \sqrt{m_S\, M_{\rm P}}$
- cosmological constraints on models with “light” flavons
- moduli problem more severe than generally appreciated

Thanks a lot!

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