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Cell and Tissue Biophysics from BioNumbers and Physical Biology of the Cell

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Cell and Tissue Biophysics

- ✓1: Aggregation
- ✓2: Signalling
- ✓3: Cytoskeleton and mobility
- ✓4: Tissue-level modelling
- ✓5: Organ-level modelling
- ✓6: Modelling of cell components

The basic background in first

- BioNumbers from
  - Harvard and Caltech (USA),
  - Weizmann Institute of Science (Israel),
  - RIKEN Quantitative Biology Center (Japan)
  - etc.
- Physical Biology of the Cell
- Theoretical biology
- Cell-to-cell communication & Biological measurement
- The fundamental constants & laws of biology

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http://bionumbers.hms.harvard.edu/

B10NUMB3R5
THE DATABASE OF USEFUL BIOLOGICAL NUMBERS

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Popular BioNumbers | Recent BioNumbers | Key BioNumbers | Amazing BioNumbers

Find Terms [ ] search

e.g., ribosome coli , p53 human , transcription , OD

Did you ever need to look up a number like the volume of a cell or the cellular concentration of ATP, only to find yourself spending much more time than you wanted on the Internet or flipping through textbooks - all without much success?

Well, it didn't happen only to you. It is often surprising how difficult it can be to find concrete biological numbers, even for properties that have been measured numerous times. To help solve this for one and all, BioNumbers (the database of key numbers in molecular biology) was created. Along with the numbers, you'll find the relevant references to the original literature, useful comments, and related numbers.

Though we have made an honest first try at simplifying the process of finding useful biological numbers, there is still much work to be done. A key challenge is filling in the large number of missing items. Please email us more useful references . Another challenge involves setting up a reliable and discriminating search engine which on a first try yields the numbers a user is actually interested in finding.

-> To cite BioNumbers please refer to: Milo et al. Nucl. Acids Res. (2010) 38: D750-D753. When using a specific entry from the database it is highly recommended that you also specify the BioNumbers 6 digit ID, e.g. "BNID 100986, Milo et al 2010".

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THE DATABASE OF USEFUL BIOLOGICAL NUMBERS

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http://openwetware.org/wiki/BioNumbers

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- Main Page
- Recent changes
- Help
- Contact OWW
- Add a Lab Notebook

research
- Materials
- Protocols
- Resources

search
Search Go ?

toolbox
- What links here
- Related changes
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contributing authors
- **Uri Moran**
- Ben Walter
- Ron Milo
- Bill Flanagan
- ShawnDouglas
- Michael Springer

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BioNumbers

Contents [hide]

BioNumbers - the database of useful biological numbers

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Key Numbers for Cell Biologists

- http://www.bionumbers.org/
- Cell size (1-3)
- Length Scales Inside Cells (4-8)
- Division, Replication, Transcription, Translation & Degradation Rates (9-12)
- Concentration (13-17)
- Energetics (18-20)
- Diffusion and Catalysis Rate (21, 22)
- Genome sizes & Error Rates (23-26)
- We can apply all above to **cell and tissue biophysics**

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Physical Biology of the Cell

- Rob Phillips Group: **Physical Biology of the Cell**
  - http://www.rpgroup.caltech.edu/
- Rob Phillips, Jane Kondev, Julie Theriot. [1st ed.] Garland Science. 2008. 826 p.
- R Phillips, J Kondev, J Theriot, N Orme, and H Garcia. [2 nd ed.] Garland Science. 2013. 1040 p.
- http://microsite.garlandscience.com/pboc2/
- Home - Physical Biology of the Cell
- PBoC@MOLPIT http://pboc.molpit.com/

Theoretical biology. Who was in first?

- **Richard Kroner**. Berlin, Gebrüder Borntraeger, **1919**. Abhandlungen zur theoretischen biologie, hft. 2
  - There was even a series "Essays on Theoretical Biology" in German at the beginning of the last century!
- **Ludwig von Bertalanffy. 1928**. *Kritische Theorie der Formbildung*. 1932. *Theoretische Biologie*: Band 1: *Modern theories of development*: an introduction to theoretical biology. Oxford University Press. 1933.
- **E.S. Bauer.** *Theoretical Biology*, Ed. VIEM, Moscow, 1935
- **Conrad Hal Waddington**
- 1939). *An Introduction to Modern Genetics*. London : George Alien & Unwin Ltd.
- 1942. Canalization of development and the inheritance of acquired characters. *Nature* **150**: 563-565.
- Waddington's epigenetic landscape is a metaphor for how gene regulation modulates development.
- 1968–1972. *Towards a Theoretical Biology*. 4 vols. Edinburgh: Edinburgh University Press.

Cell-to-cell communication

- We measure BioNumbers by Physical Equipment
- What numbers are measured by cell?
- Nobody knows, but my point of view
  - Physical signals (mechanical, electrical etc.)
  - Chemical signals
  - Biological signals
- I think: every cell measures any cell
- What equipment cell & tissue have?
- Any cellular device measure … by bio interaction

Biological measurement

- A cell measures the cell
- A cell measures the tissue
- A cell measures the others cells
- Any tissue measures the every cell
    - They use biological measures!
        - What is biomeasure?
- Let's ask Google about

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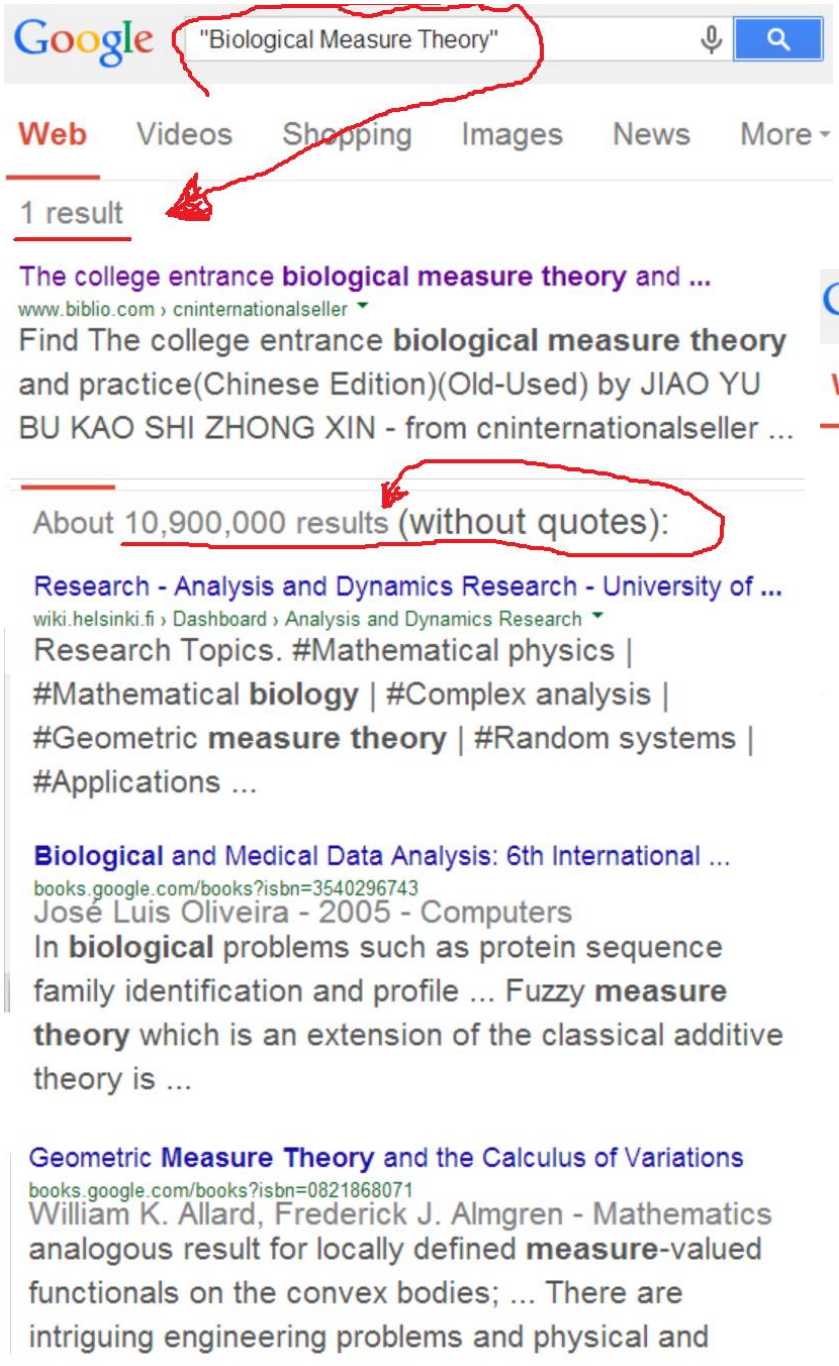
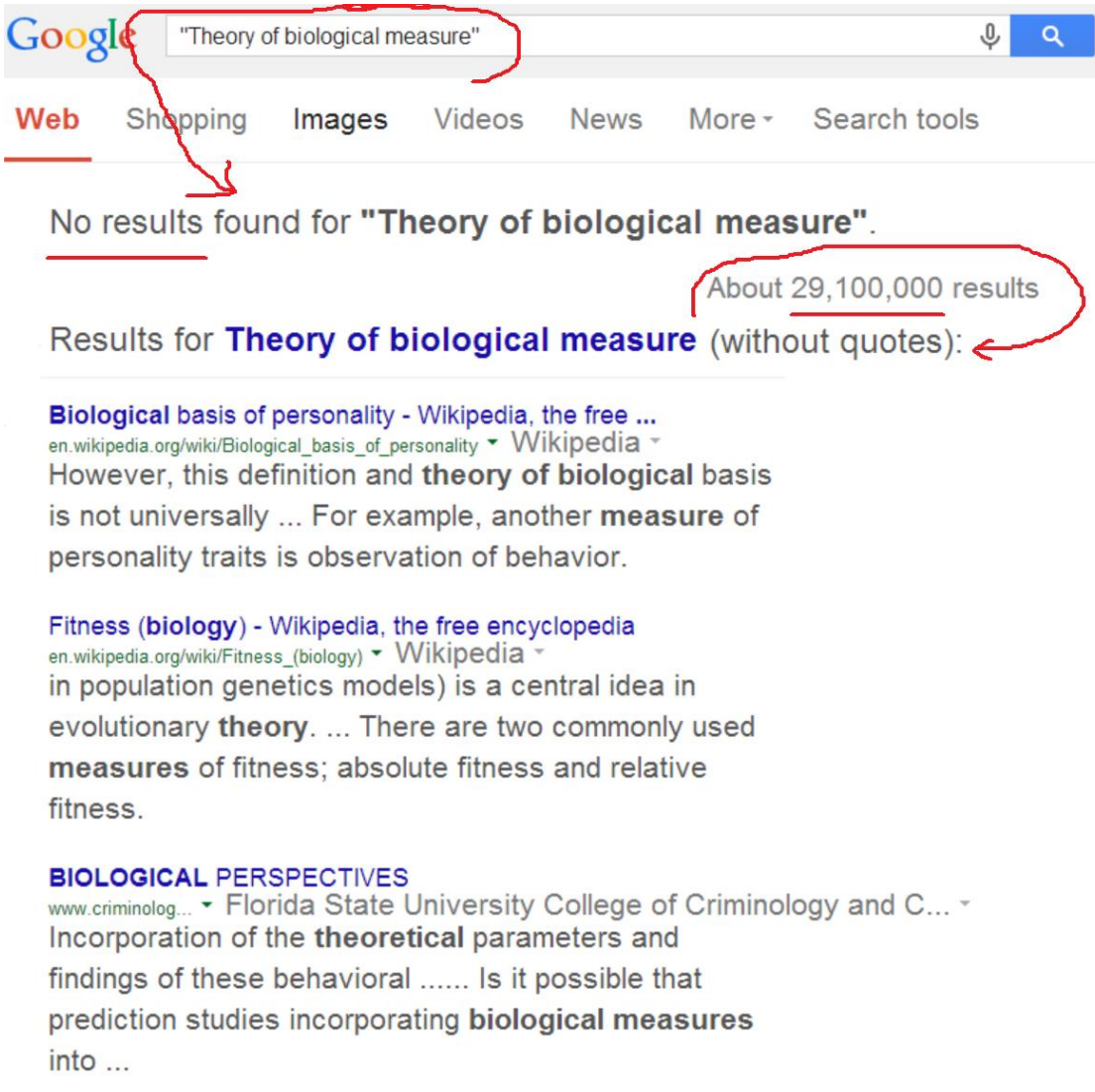
Google answers:





Theory of biological measure

- H Federer. Geometric Measure Theory. 1969
  - **Herbert Federer** is one of the creators of geometric measure theory, at the meeting point of differential geometry and mathematical analysis.
- The question arising: “Who will create biomeasure theory?” – The meeting point of cell biology and correct tissue analysis of all internal cells?
- P R Halmos. Measure Theory. 1974

  Towards Biomeasure Theory – my dreams
- In first the measures of biological interaction

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The fundamental constants & laws of biology

- Laws of biology: why so few?
  - PK Dhar, A Giuliani. *Syst Synth Biol.* **4** (1), 7-13 (2010).
- Main thoughts following from this paper
  - "at the cell-to-cell interaction, molecular networks and **tissue** levels, fundamental organizing principles remain to be discovered".
  - "universal biological constants equivalent to those of the physical constants".
  - "due to complex nature of biological organization it is difficult to think of a universal law or a theory in biology connecting all the levels, from atoms to ecosystems. One should look for generalizations at various levels instead".
- E-cell System: Basic Concepts and Applications
  - *SNV Arjunan, PK Dhar, M Tomita*. Springer, 2013. 185 p.
- Urgent note
    - BioNumbers of RIKEN Quantitative Biology Center, Japan

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To be or not to be biological laws?

- Biological laws (***Wiki*** *"Laws of science"*)
  - Life is based on cells
  - All life has genes
  - All life occurs through biochemistry
  - Mendelian inheritance
- Life's Universal Scaling Laws
  - GB West, JH Brown. Phys today 57 (9), 36-43 (2004).
- Five Biological Laws of Dr. Hamer URL
  - All medical theories, whether conventional or "alternative", past or current, are based on the concept that diseases are "malfunctions" of the organism. Dr. Hamer's discoveries show, however, that nothing in Nature is "diseased" but always biologically meaningful. According to the Five Biological Laws, diseases are not malignancies, as proposed by conventional medicine, but are instead age-old "Biological Special Programs of Nature" that assist an individual during unexpected distress.

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Are there Laws of Biology? *Steve Campbell*

- On the Nature of Belief URL **Proposed Laws of Biology**
  1) a thermodynamic law of life:
  2) a law of individuality:
  3) a law of boundary condition:
  4) a law of complexity:
  5) a law internal fluidity or aqueousness:
  6) a law of minimum elemental composition:
  7) a law of minimum chemical bond set:
  8) a law of chemical chirality:
  9) a law of minimum molecular complexity:
  10) a law of common origin:
  11) a law of ancestry:
  12) a probabilistic law of imperfect replication:
  13) a law of birth:
  14) a law of development:
  15) a law of death:
  16) a law of extinction: … (Who knows? Life is infinite!)
  17) a law of ecological necessity: … (Symbiosis)

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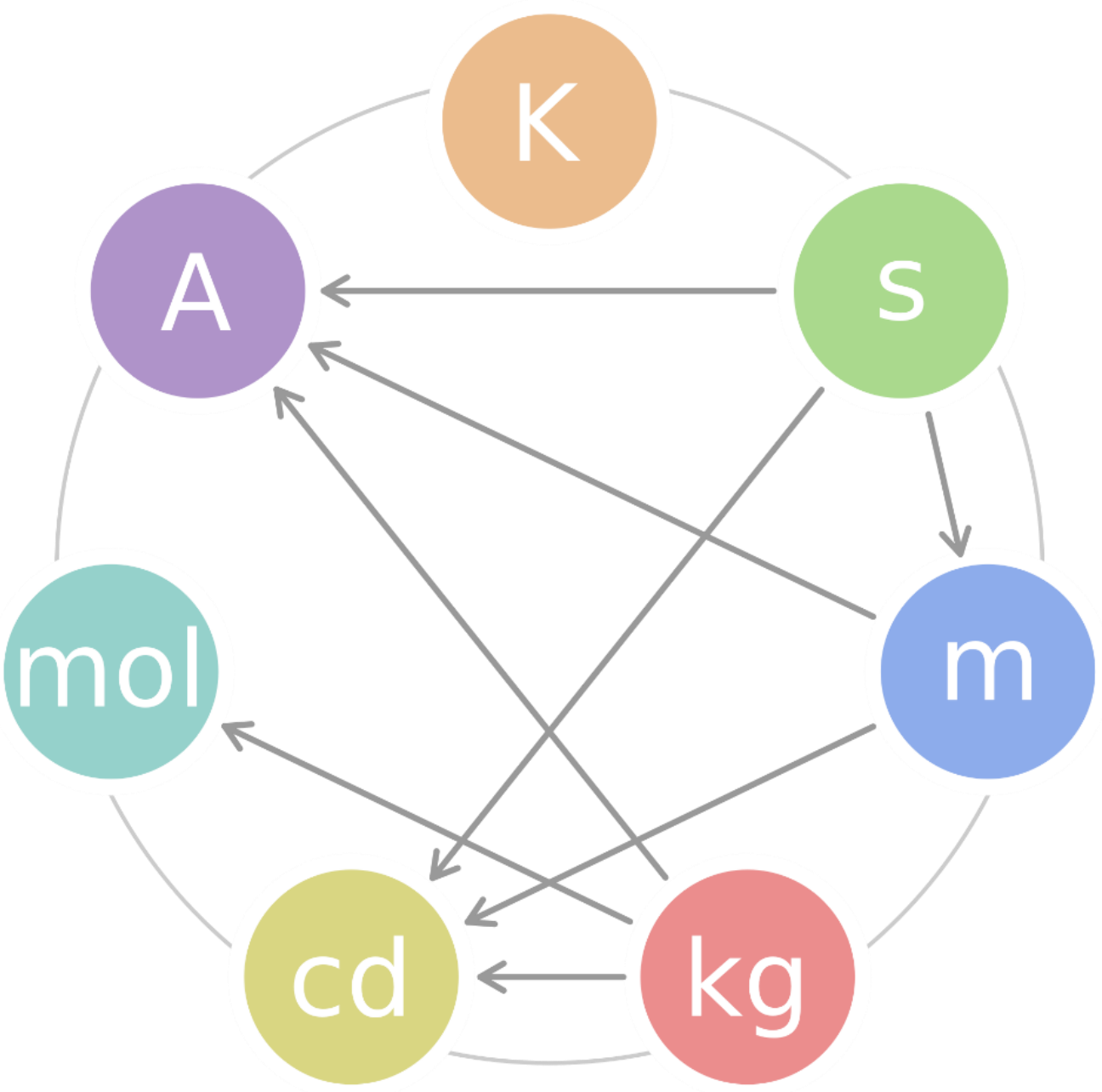

Current (2013) SI System:

Dependence of base unit definitions on other base units

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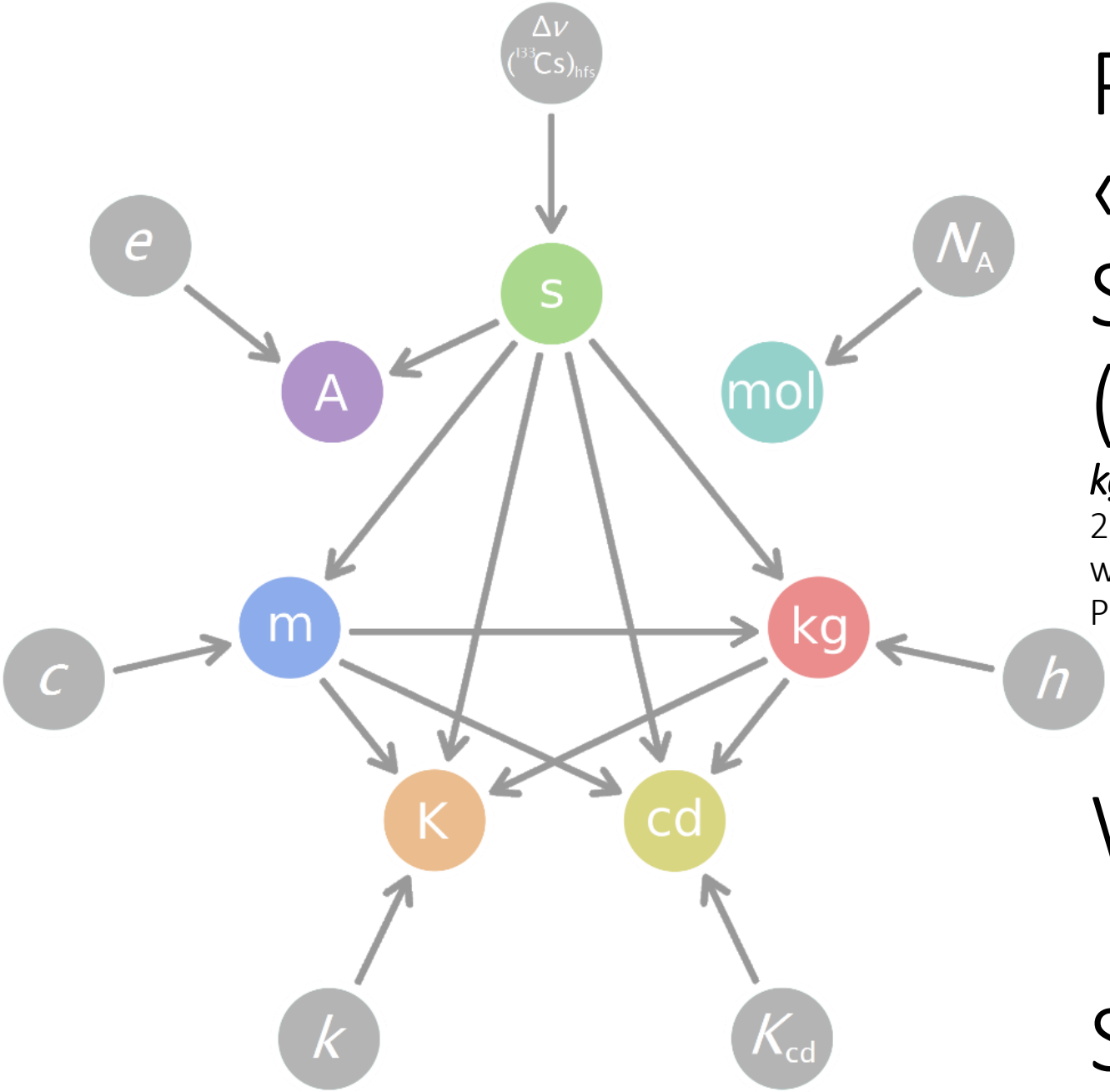

Proposed «Quantum SI» System (2014)

kg is recent artifact at SI. 25th CGPM (18 Nov 2014) will define ***kg*** in terms of the Planck constant ***h***

What about «Biological SI» System?

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Measure of biological interaction

- By Nanodiamond – Protein Collective Aggregation
- Numbers are misleading and BioNumbers too!
- Mark Twain said about: "There are three kinds of lies: lies, damned lies, and statistics.“
- But what we should use instead biostatistics?
- To study biological interaction we take into account
- individuality of every cell and every tissue
- cell and tissue integrity
- emergence of new tissues from interacting cells
- strong effect of lower levels of organization, e.g., protein, ncRNA, organelles, subcellular
- collective self-organization and multi-level effects of cells and tissues

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Biological measures & gauges Conclusions

- From Key Numbers for Cell Biologists in the field of Cell and Tissue Biophysics
- Towards BioMeasures & BioGauges
- ? who, where, when
- To make «Biological SI» System
- With Fundamental Biological Constant
- Based on «Quantum SI» System

- Let's think & act together

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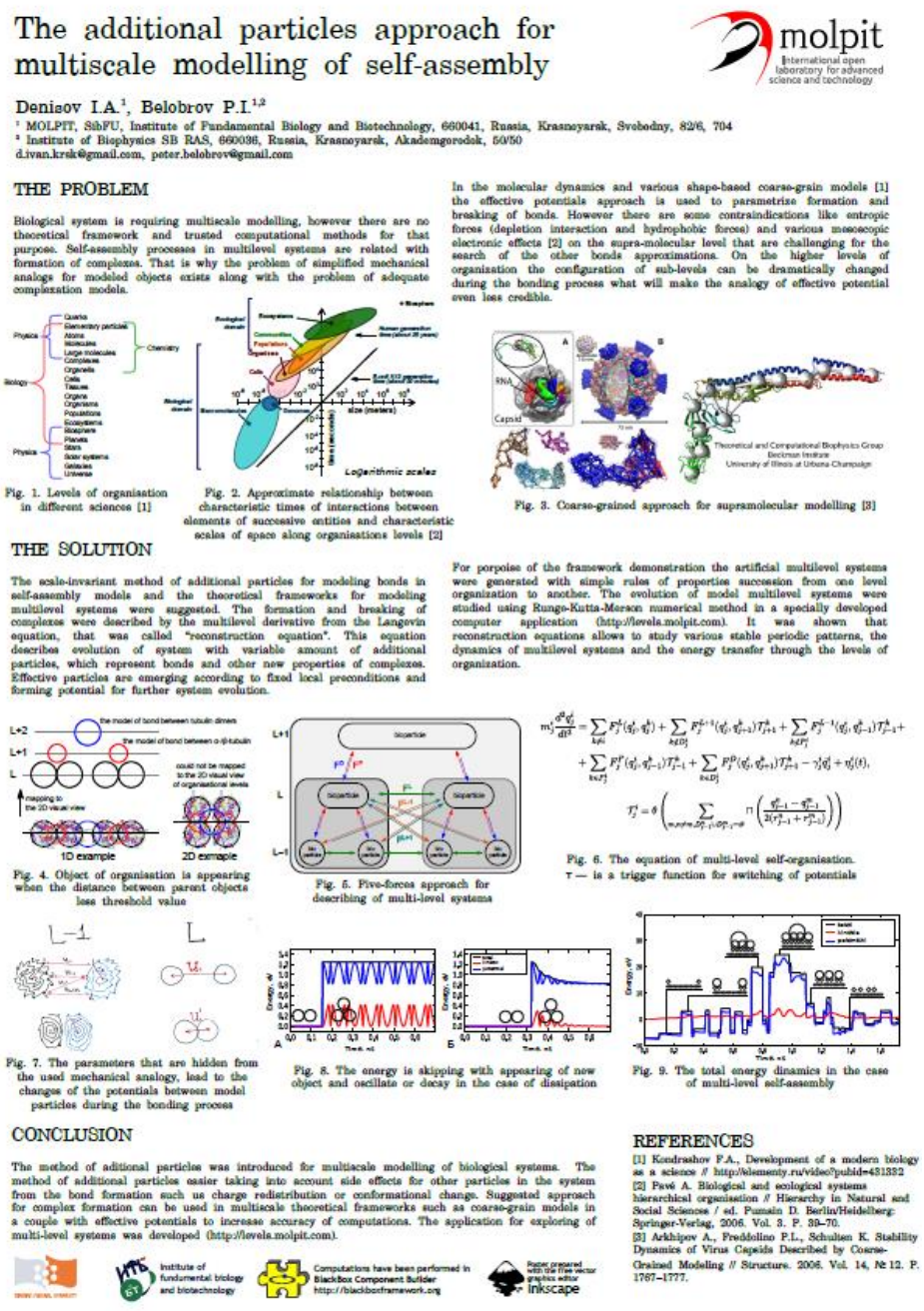
Poster #48

Ivan A Denisov, Peter I Belobrov

The method of additional particles for models of self-assembly in multilevel biological systems
->
The additional particles approach for multiscale modeling of self-assembly

Poster Sessions

Sunday 15 June: 16:00–18:00
Monday 16 June: 17:00–19:00



The additional particles approach for multiscale modelling of self-assembly

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THE PROBLEM

Biological system is requiring multiscale modelling, however there are no theoretical framework and trusted computational methods for that purpose. Self-assembly processes in multilevel systems are related with formation of complexes. That is why the problem of simplified mechanical analogs for modeled objects exists along with the problem of adequate complexation models.

In the molecular dynamics and various shape-based coarse-grain models [1] the effective potentials approach is used to parametrize formation and breaking of bonds. However there are some contraindications like entropic forces (depletion interaction and hydrophobic forces) and various mesoscopic electronic effects [2] on the supra-molecular level that are challenging for the search of the other bonds approximations. On the higher levels of organization the configuration of sub-levels can be dramatically changed during the bonding process what will make the analogy of effective potential even less credible.

Fig. 1. Levels of organisation in different sciences [1]

Fig. 2. Approximate relationship between characteristic times of interactions between elements of successive entities and characteristic scales of space along organisations levels [2]

Fig. 3. Coarse-grained approach for supramolecular modelling [3]

THE SOLUTION

The scale-invariant method of additional particles for modeling bonds in self-assembly models and the theoretical frameworks for modeling multilevel systems were suggested. The formation and breaking of complexes were described by the multilevel derivative from the Langevin equation, that was called "reconstruction equation". This equation describes evolution of system with variable amount of additional particles, which represent bonds and other new properties of complexes. Effective particles are emerging according to fixed local preconditions and forming potential for further system evolution.

For porpoise of the framework demonstration the artificial multilevel systems were generated with simple rules of properties succession from one level organization to another. The evolution of model multilevel systems were studied using Runge-Kutta-Merson numerical method in a specially developed computer application (http://levels.molpit.com). It was shown that reconstruction equations allows to study various stable periodic patterns, the dynamics of multilevel systems and the energy transfer through the levels of organization.

Fig. 4. Object of organisation is appearing when the distance between parent objects less threshold value

Fig. 5. Five-forces approach for describing of multi-level systems

$$m_j^l \frac{d^2 q_j^l}{dt^2} = \sum_{k \in J_j^l} F_j^k(q_j^l, q_j^k) + \sum_{k \in D_j^l} F_j^{l-1}(q_j^l, q_{j-1}^k) T_{j+1}^k + \sum_{k \in T_j^l} F_j^{l-1}(q_j^l, q_{j-1}^k) T_{j-1}^k +$$
$$+ \sum_{k \in T_j^l} F_j^l(q_j^l, q_{j-1}^k) T_{j-1}^k + \sum_{k \in D_j^l} F_j^D(q_j^l, q_{j+1}^k) T_{j+1}^k - \gamma_j^l \dot{q}_j^l + \eta_j^l(t),$$
$$T_j^l = \phi\left(\sum_{m,n \neq m, D_j^m, i \in D_j^n, i \neq 0} \Pi\left(\frac{q_{j-1}^n - q_{j-1}^m}{2(r_{j-1}^n + r_{j-1}^m)} \right) \right)$$

Fig. 6. The equation of multi-level self-organisation. τ — is a trigger function for switching of potentials

Fig. 7. The parameters that are hidden from the used mechanical analogy, lead to the changes of the potentials between model particles during the bonding process

Fig. 8. The energy is skipping with appearing of new object and oscillate or decay in the case of dissipation

Fig. 9. The total energy dinamics in the case of multi-level self-assembly

CONCLUSION

The method of additional particles was introduced for multiscale modelling of biological systems. The method of additional particles easier taking into account side effects for other particles in the system from the bond formation such as charge redistribution or conformational change. Suggested approach for complex formation can be used in multiscale theoretical frameworks such as coarse-grain models in a couple with effective potentials to increase accuracy of computations. The application for exploring of multi-level systems was developed (http://levels.molpit.com).

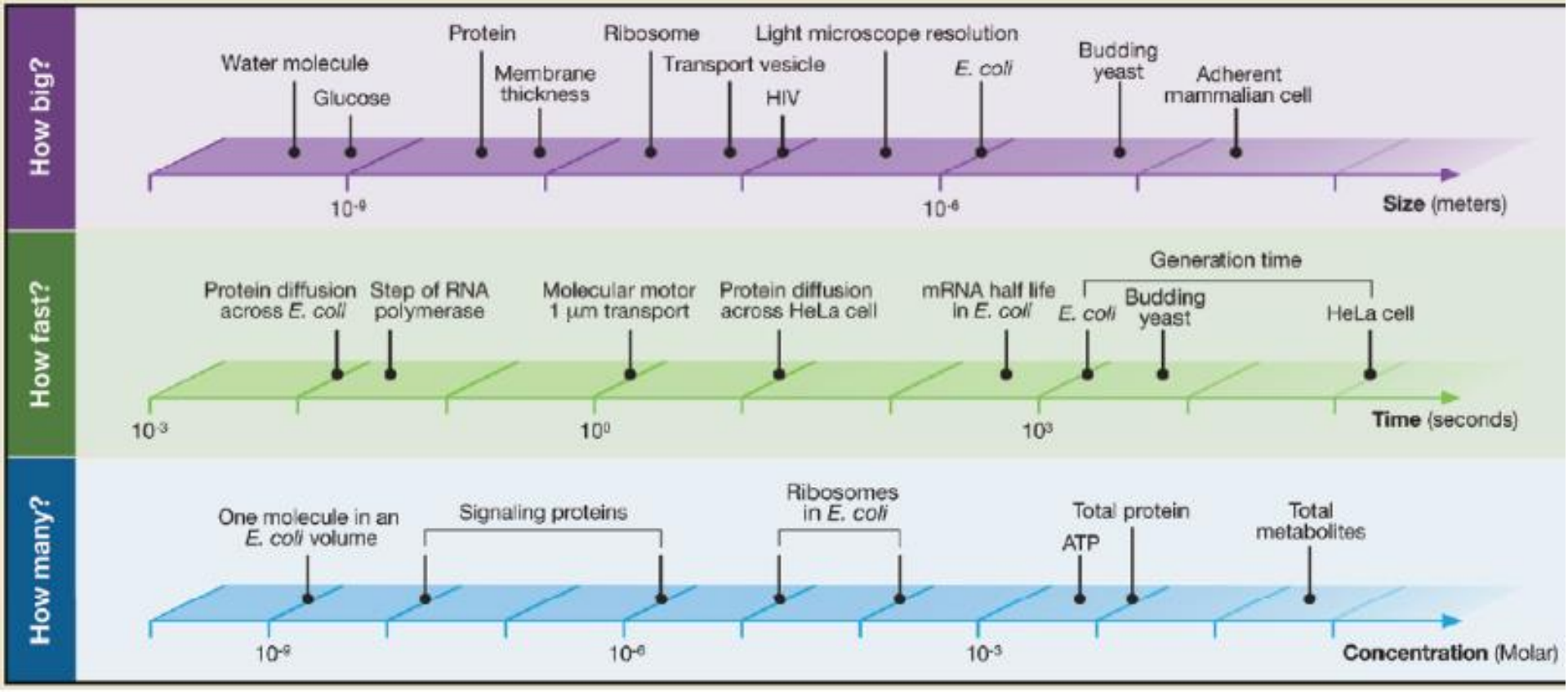
REFERENCES

[1] Kondrashov F.A., Development of a modern biology as a science // http://elementy.ru/video?pubid=431332
[2] Pavé A. Biological and ecological systems hierarchical organisation // Hierarchy in Natural and Social Sciences / ed. Pumain D. Berlin/Heidelberg: Springer-Verlag, 2006. Vol. 3. P. 39–70.
[3] Arkhipov A., Freddolino P.L., Schulten K. Stability Dynamics of Virus Capsids Described by Coarse-Grained Modeling // Structure. 2006. Vol. 14, № 12. P. 1767–1777.

Institute of fundamental biology and biotechnology
Computations have been performed in BlackBox Component Builder http://blackboxframework.org
Inkscape

SnapShot: key numbers in biology

- Uri Moran, Rob Phillips, Ron Milo. SnapShot: key numbers in biology // *Cell*, **141** (7), 1262 (2010).



http://www.bionumbers.hms.harvard.edu/KeyNumbers.aspx?redirect=false

Key Numbers for Cell Biologists

Cell sizes:

1. Bacteria (*E. coli*): ≈0.7-1.4 μm diameter, ≈2-4 μm length, ≈0.5-5 μm^3 in volume; 10^8-10^9 cell/ml for culture with OD_{600}≈1
2. Yeast (*S. cerevisiae*): ≈3-6 μm diameter, ≈20-160 μm^3 in volume
3. Mammalian cell volume: 100-10000 μm^3; Hela: 500-5000 μm^3 (adherent on slide ≈15-30 μm diameter)

Length Scales Inside Cells

4. Nucleus volume ≈10% of cell volume
5. Cell membrane thickness ≈4-10 nm
6. "Average" protein diameter ≈3-6 nm
7. Base pair: 2 nm (D) x 0.34 nm (H)
8. Water molecule diameter ≈0.3 nm

Division, Replication, Transcription, Translation & Degradation Rates

at 37°C with a temperature dependence Q10 of ≈2-3

9. Cell cycle time (exponential growth in rich media): *E. coli* ≈20-40 min; yeast 70-140 min; human cell line (Hela): 15-30 hours
10. Rate of replication by DNA polymerase *E. coli* ≈200-1000 bases/s; human ≈40 bases/s. Transcription by RNA polymerase 10-100 bases/s
11. Translation rate by ribosome 10-20 aa/s
12. Degradation rates (proliferating cells): mRNA half life < cell cycle time; protein half life ≥ cell cycle time

Concentrations

13. Concentration of 1 nM in: *E. coli* is ≈1 molecule/cell; Hela ≈1,000 molecules/cell
14. Characteristic concentration for a signaling protein ≈10 nM-1 μM
15. Water content: ≈70% by mass; General elemental composition (dry weight) of *E. coli*: ≈$C_4H_7O_2N_1$; Yeast ≈$C_6H_{10}O_3N_1$
16. Composition of *E. coli* (dry weight): ≈55% protein, 20% RNA, 10% lipids, 15% others
17. Protein conc. ≈100 mg/ml=3 mM. 10^6-10^7 per *E. coli* (depending on growth rate); Total metabolites (MW<1kD) ≈300mM

Energetics

18. Membrane potential ≈70-200 mV → 2-6 k_BT per electron (k_BT=thermal energy)
19. Free energy (ΔG) of ATP hydrolysis under physiological conditions ≈40-60 kJ/mole → ≈20k_BT/molecule ATP; ATP molecules required to make an *E. coli* cell ≈10-50×10^9
20. ΔG^0 resulting in order of magnitude ratio between products and reactants concentrations: ≈6 kJ/mol = ≈60 meV = ≈2 k_BT

Click on a number to see full description and reference: www.BioNumbers.org

Diffusion and Catalysis Rate

21. Diffusion coefficient for an "average" protein: in cytoplasm D≈5-15 $\mu m^2/s$ → ≈10 millisec to traverse an *E. coli* →≈10 s to traverse a mammalian (Hela) cell; small metabolite in water D≈500 $\mu m^2/s$
22. Diffusion limited on-rate for characteristic protein ≈10^8-10^9 $s^{-1}M^{-1}$ → for a protein substrate of concentration ≈1μM the diffusion limited on-rate is ≈10-100 s^{-1} thus limiting the catalytic rate k_{cat}

Genomes, Mutation & Error Rates

23. Genome size: *E. coli* ≈4×10^6 bp; *S. cerevisiae* (yeast) ≈12×10^6 bp; *C. elegans* (nematode) ≈100×10^6 bp; *D. melanogaster* (fruit fly) ≈120×10^6 bp; *A. thaliana* (arabidopsis) ≈160×10^6 bp; *M. musculus* (mouse) ≈3,000×10^6 bp; *H. sapiens* (human) ≈3,000×10^6 bp; *T. aestivum* (wheat) ≈17,000×10^6 bp
24. Mutation rate in DNA replication ≈10^{-10} per bp
25. Misincorporation rate: transcription ≈10^{-4} per nucleotide; translation ≈10^{-3}-10^{-4} per amino-acid

Useful biological numbers extracted from the literature. Numbers and ranges should only serve as "rule of thumb" values. References are in the online annotated version at the BioNumbers website. Consult website and original references to learn about the details of the system under study including growth conditions, method of measurement, etc.

Home - Physical Biology of the Cell

- http://microsite.garlandscience.com/pboc2/data.html
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- http://microsite.garlandscience.com/pboc2/hints.html
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Home
Data
Hints
Mathematica® & Matlab® Codes
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Physical Biology of the Cell, Second Edition

Welcome to the Student & Instructor Resource Website for Physical Biology of the Cell!

This website provides electronic resources for teaching and additional study. We hope these resources will help the reader explore the interface between biology and physics in a detailed way that directly complements the text. The following resources are available:

Data

The original data used to create both the figures and homework problems are available. With this data, the reader can extend the theoretical tools developed in the book to fit experimental data for a wide range of problems. The data files contain explicit statement of all relevant units, and include references to the original sources.

Hints

We have provided both hints and strategies for attacking some of the more difficult end-of-chapter problems. In some cases, the hints provide intuition about how to set up the problem; in other cases, the hints provide explicit mathematical instructions on how to carry through more tricky manipulations.

Mathematica® & Matlab® Codes

The Computational Exploration sidebars in the book feature simple computer analyses to solve problems that would otherwise be inaccessible. Matlab and Mathematica code related to most of the Computational Explorations is provided here for further computation, visualization, and analysis. For a selection of figures and end-of-chapter problems, many algebraic steps were performed or confirmed with a very powerful computational tool known as Mathematica. In addition, we have often used Mathematica to construct figures, such as the vector fields associated with phase portraits.

PowerPoint® Presentations

The PowerPoint presentations contain the figures and micrographs from the book. There is one presentation for each chapter.

JPEGs

This archive contains the figures and micrographs from the book in JPEG format. It is organized by chapter.

Videos

The videos complement the figures and discussion from the book by illustrating the rich dynamics exhibited by living organisms and the molecules that make them tick.

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BioTheory

Поиск по сайту

- Теоретическая биология
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  - ! ESMTB
    - ECMTB 2014
  - ! Methods
  - ! Quantitative Biology
  - Amoebas
  - Apoptosis
  - Bio Math
  - Bio Motors
  - Bio Phys
  - Biology Web
  - Biomathics
    - PL Simeonov
  - Blood-Brain Barrier
  - Cerebrospinal fluid
  - Ecology
  - Evolution
  - Good Books
    - Alberts
    - Gilbert S F
    - Libbert, Eike
    - Lodish
  - Good Lectures

Теоретическая биология

Ar | El | En | Es | Fr | Ge | It | Iw | Ja | No | Sv | zh-CN

Крупные открытия в биологии требуют нового теоретического анализа и синтеза.

- РНК интерференция, роль малых РНК, успешные опыты по «искусственной жизни» — мир РНК постоянно дарит сюрпризы.
- Эпигенетика пополнились новыми фактами, которые не вписываются в традиционные представления.
- Морфогенез постоянно дополняется качественно новыми представлениями.
- Экспериментальные исследования клеточных и молекулярные моторов поставили ряд новых вопросов.
- Рождается содержательная количественная биология.

Сейчас многие биологические открытия не случайно являются революционными.

Этот сайт создан для изложения основных фактов современной биологии. Знание их питает новые идеи правильного взгляда на природу биологических процессов в целом.

Подстраницы (19): 1 Key words Бауэр Белинцев Б Н Белоусов Б П Белоусов Л В Берталанфи Тьюринг Уоддингтон фон Нейман ! Цель и задачи Черданцев В Г Чураев Шишкин М А Эволюция Эйген (Eigen) М Япония Jakob von Uexküll 1926 Joseph Henry Woodger Kalevi Kull

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http://tbio.molpit.ru/ Translate From: Russian To: English

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BioTheory

Site Search

Theoretical Biology

Ar El En Es Fr Ge It Iw Ja No Sv zh-CN

Major discoveries in biology require a new theoretical analysis and synthesis.

- RNA interference, the role of small RNAs, successful experiments on "artificial life" - RNA world constantly brings surprises.
- Epigenetics replenished with new facts that do not fit into traditional ideas.
- Morphogenesis is constantly supplemented qualitatively new ideas.
- Experimental study of cellular and molecular motors have put a number of new questions.
- Born meaningful quantitative biology.

Now many biological discoveries are not accidental revolutionary.

This site was created to outline the basic facts of modern biology. Knowledge nourishes their ideas correct view of the nature of biological processes in general.

Subpages (19): 1 Key words Bauer Belintsev BN Belousov BP Belousov LV Bertalanffy Turing Waddington von Neumann ! The purpose and objectives Cherdantsev C Churaev Shishkin MA Evolution Eigen (Eigen) M Japan Jakob von Uexküll 1926 Joseph Henry Woodger Kalevi Kull

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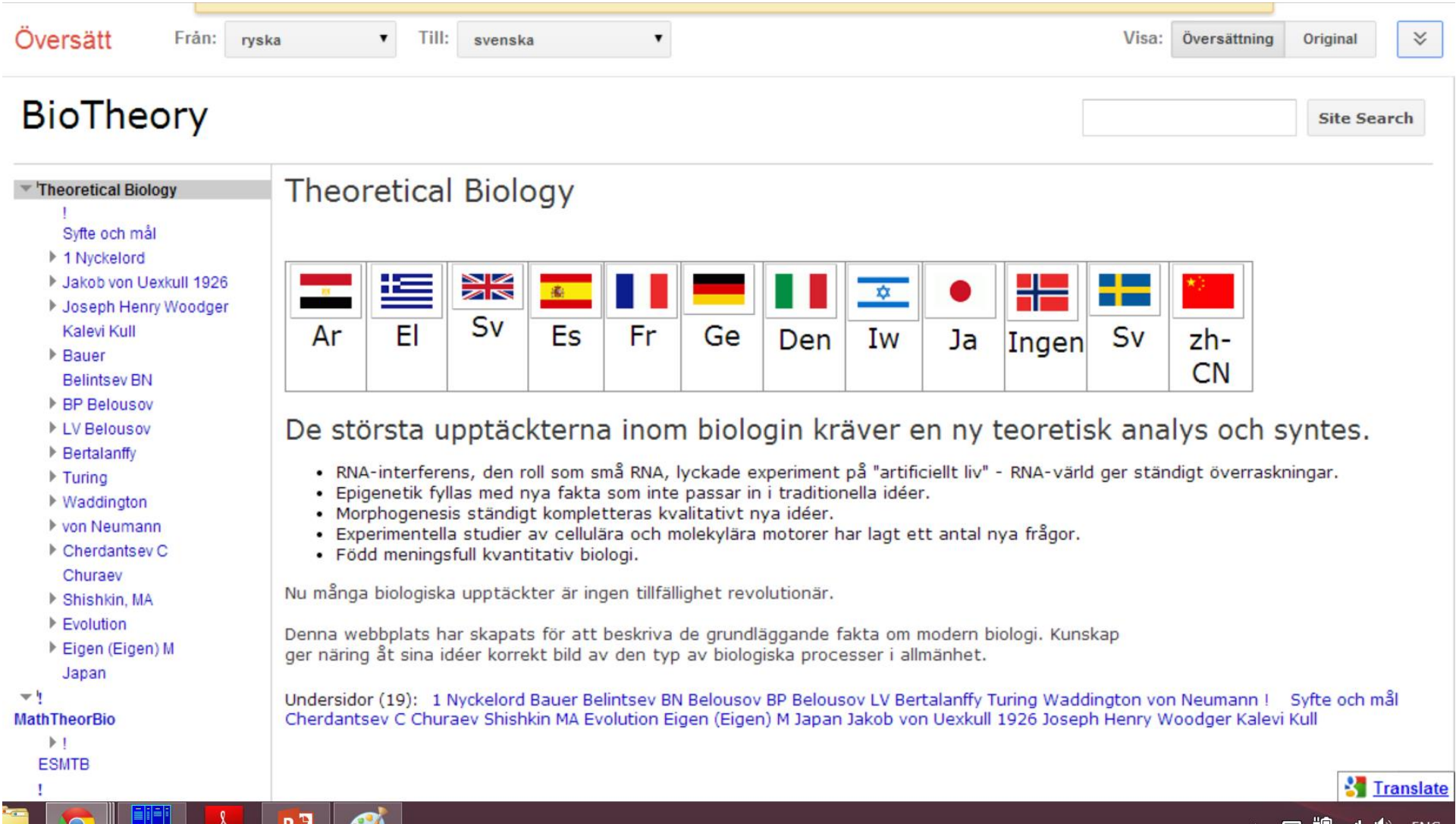

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Cell-to-cell microfluidic interaction models in Cell and Tissue Biophysics

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Cell-to-cell microfluidic interaction models in **Cell and Tissue Biophysics**

- We provide here detailed discussion on the introduction of biological measures and on the nature of the biological signals. The theory of absolute and relative biological measures has been briefly analyzed in case of mutual cell-cell and cell-tissue measurement.
- We focus on the biological signals and droplet microfluidic principles of cell-cell interaction modeling and biological measurements. Analysis of the theory of network organization with similar properties of structures and functions of biological particles are presented in the overview, and theory of collective multilevel hierarchical organization that can form the basis of the description of the internal structures and relative biological measures is proposed.
- We further analyze possible applications of the discussed theoretical approaches to understand the measurement problems in modern biology and in the science of health.

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Nanodiamond – Protein Collective Aggregation

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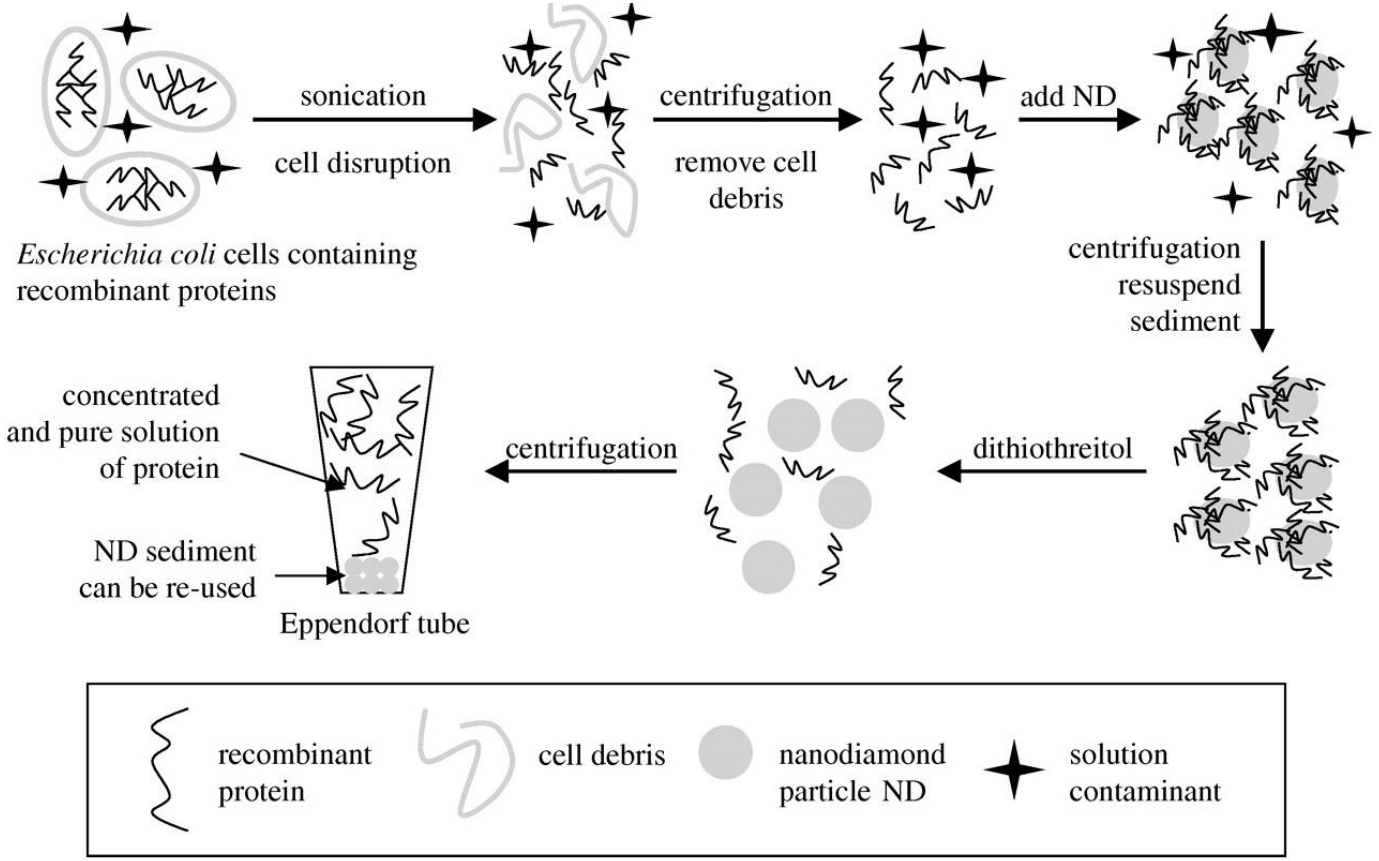
Scheme for separation and purification of the recombinant protein from *Escherichia coli* cells using adsorption of proteins onto detonation ND (using the procedure described by Bondar et al. 2004).



Holt K B *Phil. Trans. R. Soc. A* **365**, 2845 (2007); Bondar V S et al. *Phys. Sol. State* **46**, 758 (2004).