
Cells: The Building Blocks of Life

Primary Knowledge (PK)

Participant Guide

Description and Estimated Time to Complete

This learning module provides a review of “cells”, the smallest unit exhibiting the properties of life. It discusses how these cells are being used in bioMEMS as well as other micro and nano-sized devices. A research activity provides the opportunity to further explore how cells can be used in bioMEMS (bio MicroElectroMechanical Systems).

This PK unit provides information on cells, the building blocks of life, and how bioMEMS are being used in identify, analyze and cultivate cells. This information is necessary to better understand how bioMEMS use cells to create new diagnostic and therapeutic devices.

A Glossary of Key Terms is provided at the end of this unit.

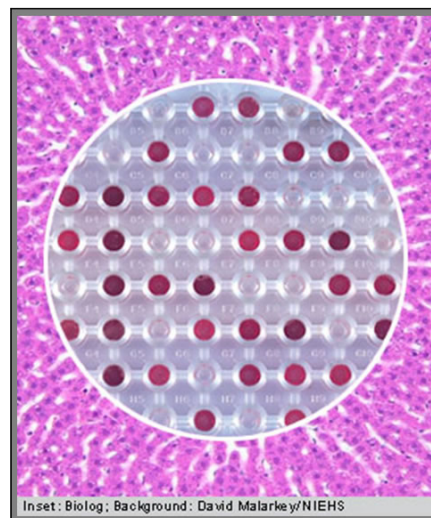
Estimated Time to Complete

Allow approximately 20 minutes

Introduction

What is a cell? Why should a person who is interested in bioMEMS learn about a cell? Because the field of bioMEMS is rapidly growing. One area that has seen quite a bit of growth over the years is the development of miniature and portable instrumentation for cell-based microassays and sensor applications.

The image on the right is from the Phenotype MicroArray™ (PM), a tool that offers a panoramic view of cellular events or properties (phenotypes). Just like a battery of tests on a person's blood can scan the health of vital organs, the PM can scan the physiology of cells, yielding data on hundreds of traits at once. Typical cell-based assays measure only one trait at a time (for example, cell death or DNA synthesis), but the PM can measure up to 2,000 traits--or phenotypes--under hundreds of growth conditions.¹ The PM is a valuable tool that leads to the development of safer and more effective drugs by allowing us to better understand how a gene or drug affects living cells.¹¹



The Phenotype MicroArray™ (PM)
Environmental Health Perspectives Volume 114, Number 3, March 2006

Some challenges facing investigators include

- how to incorporate living cells into sensors and diagnostic devices,
- how to create environmental conditions conducive to cell organization into tissue-like structures, and
- how to sort and concentrate bacterial cells on a micro-fluidic biochip.

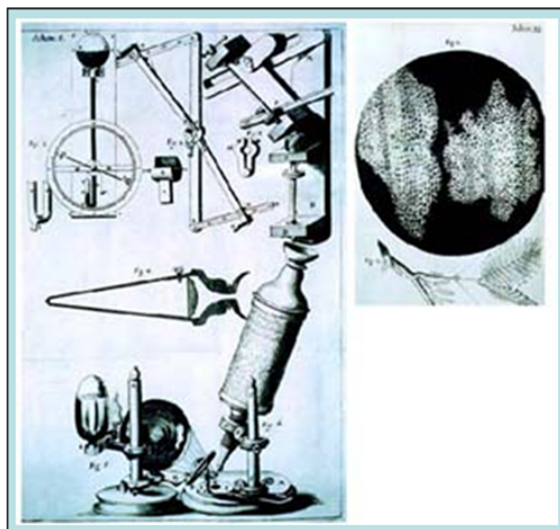
Applications in both diagnostic and therapeutic areas such as health diagnostics, environmental risk management, and food safety, are just a few of the areas impacted. All areas rely on a basic knowledge of a cell.

To a biologist, a cell is the smallest unit exhibiting the property of life. Cells acquire and use energy; they acquire and organize materials; they grow and reproduce. This unit introduces the different types of cells, aspects of their growth, and the types of organelles found within cells.

Objectives

- Define and interpret the Cell Theory.
- Describe similarities and differences of prokaryotic and eukaryotic cells.
- Identify and describe the functions of cellular structures (cell membrane, cell wall, nucleus, cytoplasm, chloroplast, mitochondria) within a cell.

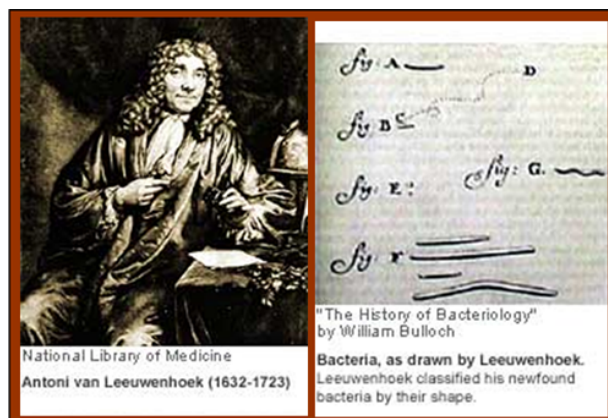
Hooke's Microscope



Robert Hooke's microscope and drawing of a thin layer of cork

Cells are small, approximately 10x smaller than the visual limits of the human eye. Thus, the discovery of cells was dependent on the development of the microscope, a tool that aided the human eye. In 1662, Robert Hooke built a primitive microscope and used it to observe and describe individual cells of cork. The illustration above shows the microscope used by Robert Hooke and a drawing of the cork showing individual cells or compartments.

Leeuwenhoek's Observations

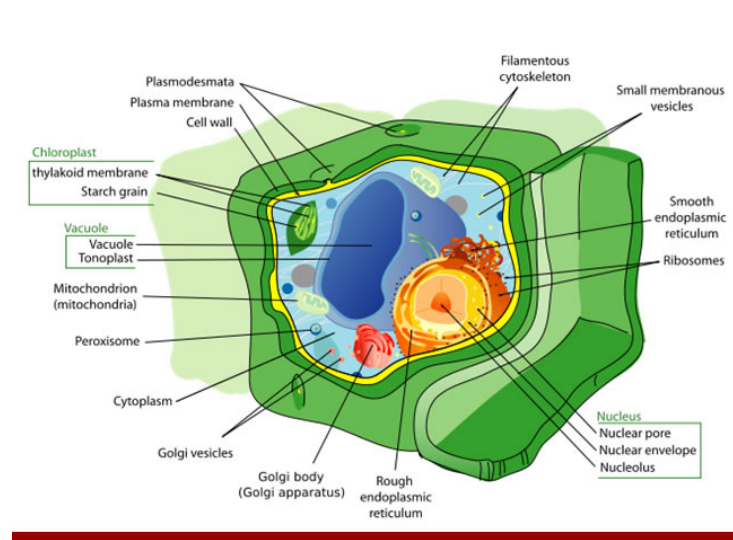


Anton van Leeuwenhoek and his drawings of microorganisms

In 1675, Anton van Leeuwenhoek used a microscope to examine droplets of water. He described a multitude of "animalcules", thus becoming the first person to observe living, single-celled microorganisms.³

Leeuwenhoek's work generated a great deal of excitement; however, it was another 100 years before scientists would describe cells in greater detail.

The Cell Theory



Plant Cell

[Image courtesy of Mariana Ruiz Villarreal]

In the 1830's, Matthias Schleiden and Theodor Schwann proposed a set of hypotheses that came to be called the cell theory. The cell theory states

- (1) all organisms are composed of one or more cells
- (2) the cell is the structural unit of life
- (3) cells can arise only by division from a preexisting cell

Prokaryotic and Eukaryotic Cells

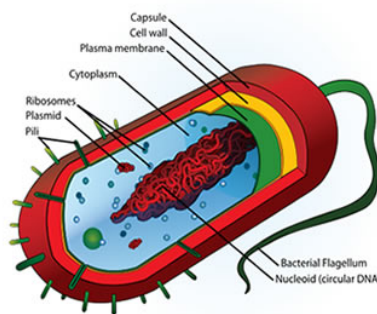


Fig 1

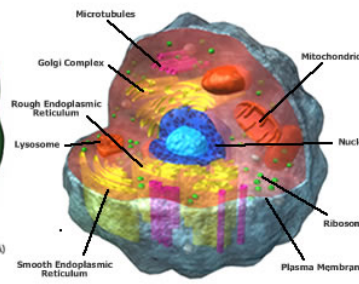


Fig 2

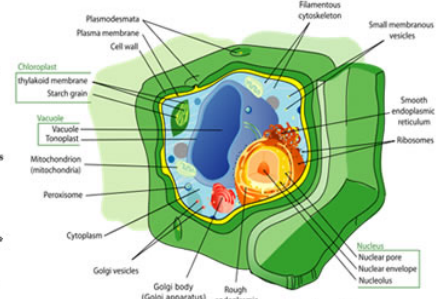


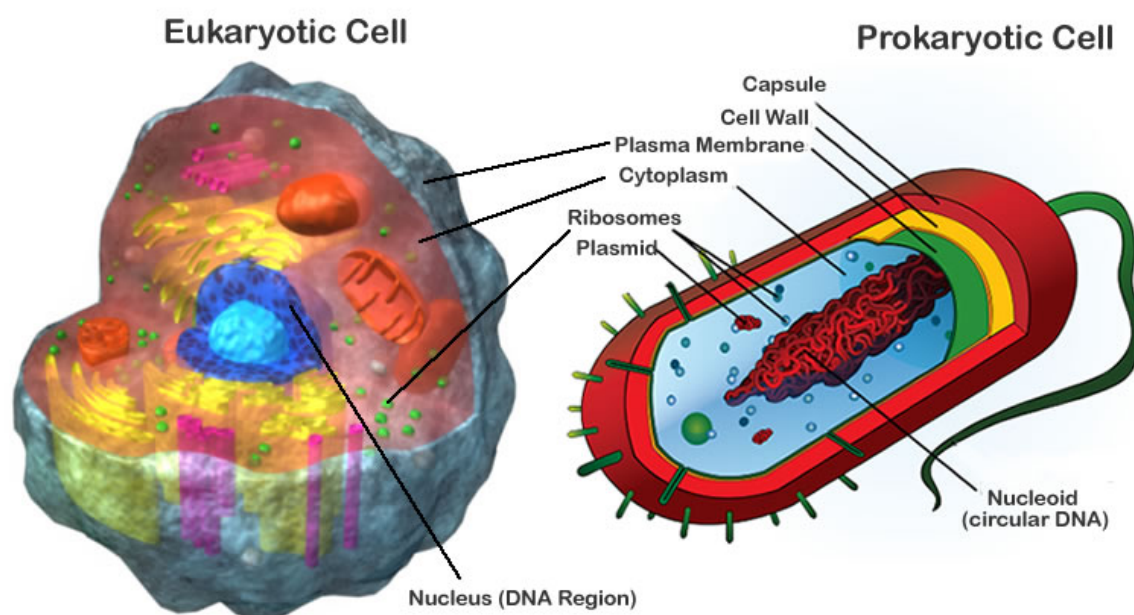
Fig 3

Bacteria, Animal cell, Plant cell

[Bacteria and Plant cell graphics courtesy of Mariana Ruiz Villarreal]

Cells vary in the types and complexity of structures found both internally and externally. However, they can be categorized into two broad types: Prokaryote and Eukaryote. The structurally simpler prokaryotic cells include bacteria (Fig 1), and the more complex eukaryotic cells include protists, fungi, animals (Fig 2) and plants (Fig 3).

Prokaryotic and Eukaryotic Cells



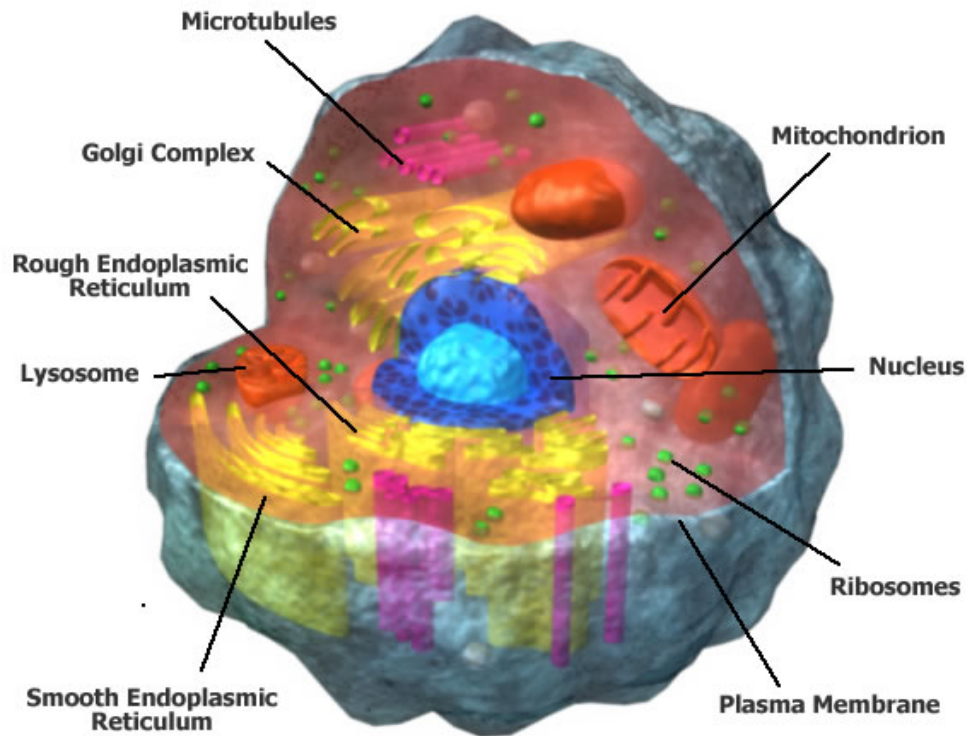
Common features of Eukaryotic and Prokaryotic cells

This figure compares eukaryotic and prokaryotic cells. It points out common features found in both cell types. Despite these common features, many characteristics distinguish these two types of cells. The table lists some of the differentiating features between prokaryotic and eukaryotic cells.

	Prokaryotic Cell	Eukaryotic Cell
Presence of a nucleus	Absent	Present
Complex membrane-bound cytoplasmic organelles	Absent	Present
Complex cytoskeletal system	Absent	Present
Cellulose-containing cell walls (plants)	Absent, contain cell walls made of different materials	Present in plants
Complex chromosomes composed of DNA and associated proteins	Absent, usually a single circular DNA molecule	Present
Size	Very small (0.1-10 mm)	Small (10-100 mm)

Table 1: Distinguishing Characteristics of Prokaryotic and Eukaryotic Cells

The Eukaryotic Cell



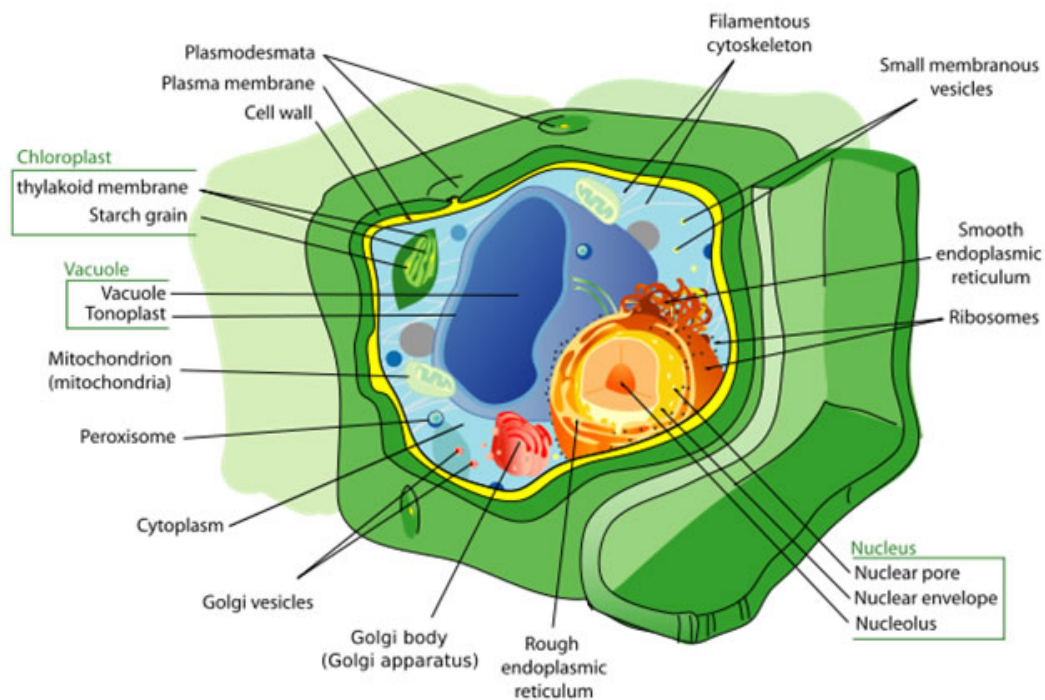
The Eukaryotic Cell

Compartmentalization is the key to eukaryotic cell function. Eukaryotic cells are larger and more structurally complex than prokaryotic cells. This complexity is largely due to the membrane-bound organelle that compartmentalizes cellular functions.

The cell nucleus is the command center of the cell. Surrounded by a porous, double membrane called the nuclear envelope, the nucleus contains the cell's hereditary material (DNA and associated proteins) organized into chromosome.

Eukaryotic cells contain an extensive endomembrane system consisting of the endoplasmic reticulum (both smooth and rough forms), the Golgi apparatus, and lysosome. These organelles form an interconnected set of membrane systems that function in compartmentalizing, transporting, and modifying proteins. The lysosomes contain digestive enzymes that break down proteins, carbohydrates, and lipids. Lysosomes process cellular debris as well as food particles.

Organelles



*Plant Cell showing organelles, Cytoplasm, Plasma Membrane and Cell Wall
[Image courtesy of Mariana Ruiz Villarreal]*

Two organelles, mitochondria and chloroplasts, function specifically to supply energy to cells. Nearly all eukaryotic cells contain mitochondria. Chloroplasts are found only in photosynthetic cells such as plants and algae (see graphic).

All of the organelles are found within the cytoplasm of the cell. For animal cells, the boundary of the cell is defined by the plasma membrane. For plant cells, the boundary is defined by the plasma membrane plus a cell wall composed of cellulose (see graphic). The structure of the animal cell is in part maintained by an extensive cytoskeletal system composed of actin microfilaments, microtubules, and intermediate filaments.

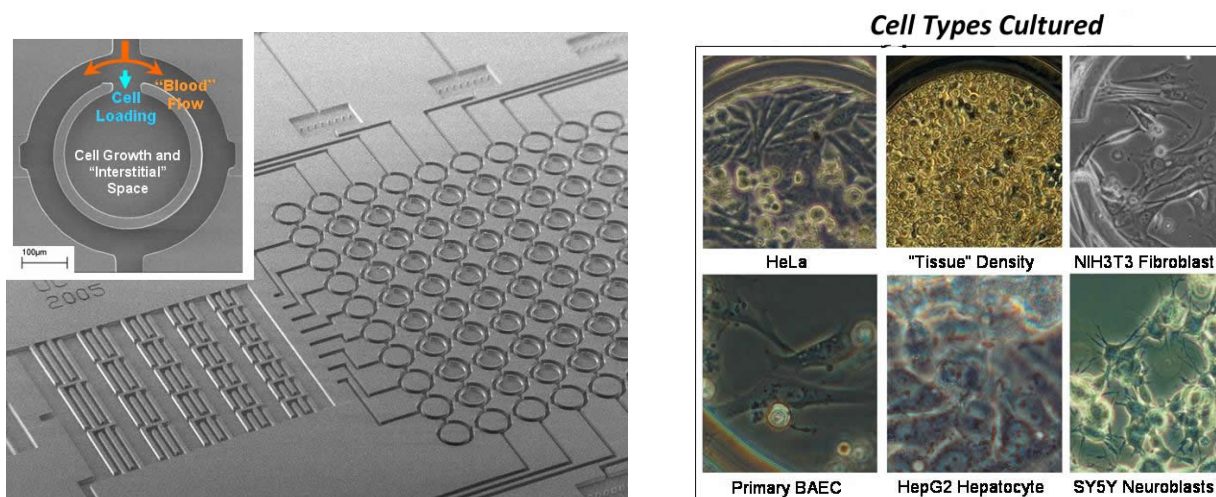
Growing Cells and MEMS Arrays

Whole cells can be removed from a plant or animal and cultured in a laboratory. In the lab they grow and reproduce for extended periods of time given optimal environmental conditions. Cells grown in vitro have become essential tools for the cell and molecular biologist.

Applications for animal cell cultures include the following:¹⁰

- Investigate the physiology or biochemistry of cells (e.g. cell metabolism).
- Test the effect of various chemical compounds or drugs on specific cell types (normal or cancerous cells, for example).
- Assist in the generation of artificial tissues (e.g. artificial skin or organ tissue).
Generating artificial tissues is an emerging area of biotechnology known as “tissue engineering”.
- Synthesize valuable biologicals from large scale cell cultures. Biologicals encompass a broad range of cell products (e.g. specific proteins or viruses, therapeutic proteins)

MEMS are being developed and tested that challenge the current tools used for cell cultivation. BioPOETS at the University of California, Berkeley has developed a MEMS cell culture array (*below left*). The array used microfluidics to create an optimal micro-environment for cell cultivation. The right images are cells that have been cultivated in this array.



MEMS Cell Culture Array (left). This array creates a microenvironment for growing cells in vitro and in parallel, allowing for the analysis of multiple cell growth conditions. The inset left shows the microenvironment of each array component. The cells on the right were grown in the cell culture array developed at the BioPOETS Lab, UC-Berkeley.

[Developed by and courtesy of BioPOETS Lab, UC-Berkeley]

To read more about this array, read “[Microfluidic Cell Culture Array](http://biopoets.berkeley.edu/cell-culture-array/)”, BioPoets, UC-Berkely.

Summary

A cell is the basic unit of life. Cells are highly complex and organized, possess hereditary information and the means to use it, reproduce, acquire and utilize energy, carry out a variety of chemical reactions, engage in mechanical activities, respond to stimuli, and self-regulate.

Cells are divided into two main categories: prokaryotic and eukaryotic. Prokaryotic cells and eukaryotic cells share similarities, but eukaryotic cells are more complex structurally. The organelles found in the larger eukaryotic cell compartmentalize cellular functions. Both types of cells can be grown in the laboratory.

MEMS applications will aid in the cultivation of cells for the purpose of creating new diagnostic and therapeutic bioMEMS.

Food for Thought / Answers

1. What are the major tenets of the cell theory?
2. How are prokaryotic and eukaryotic cells similar?
3. How are prokaryotic and eukaryotic cells different?
4. What is the primary tool of the cell biologist studying cells in the laboratory?
5. How are MEMS being used in cell cultivation?

Glossary of Key Terms

Actin microfilament - Part of the cytoskeleton of eukaryotic cells, composed of fibrous actin, functioning in cellular structure and locomotion.

Cell membrane - A semipermeable membrane that encloses the cytoplasm of a cell.

Cell wall - The rigid outermost cell layer found in plants and certain algae, bacteria, and fungi, but characteristically absent from animal cells.

Cell Nucleus - The largest of the membrane-bounded organelles found in eukaryotic cells. The nucleus contains the genetic information of the cell (DNA).

Chromosome - A linear strand of DNA and associated proteins found in the nucleus of eukaryotic cells that contains genes and functions in the transmission of hereditary information.

Cytoskeleton - The internal framework of a cell composed mainly of actin microfilaments and microtubules.

Cytoplasm - A complex, semifluid, translucent substance found outside the nucleus of a cell. It is composed of proteins, fats, and other molecules suspended in water.

Chloroplast - A subcellular organelle contain chlorophyll found in algal and green plant cells.

Eukaryote - A single-celled or multicellular organism whose cells contain a distinct membrane-bound nucleus.

Lysosome - A membrane-bound organelle found in the cytoplasm of most cells containing hydrolytic enzymes that function in intracellular digestion.

Microtubule: A structure found in eukaryotic cells that is composed of protein, provides structural support, and assists in cellular locomotion and transport.

Mitochondria - A subcellular organelle found in eukaryotic cells that use oxygen. They are responsible for energy generation by the process of oxidative phosphorylation.

Organelles – Organelles are subcellular structures that provide internal compartmentalization and other functions. An organelle is to a cell as an organ is to the body.

Prokaryote - An organism of the kingdom monera (or Prokaryotae), comprising the bacteria and cyanobacteria, characterized by the absence of a distinct, membrane-bound nucleus or membrane-bound organelles, and by DNA that is not organized into chromosomes.

References and Additional Reading

- ¹ "Cell Scenario: A New Look at Microarrays". Environmental Health Perspectives Volume 114, Number 3, March 2006.
- ² "Fundamentals of BioMEMs and Medical Microdevices". Steven S. Saliterman. Wiley Interscience. 2006.
- ³ Life: The Science of Biology, 8th edition, Sadava • Heller • Orians • Purves • Hillis. W.H. Freeman. 2007.
- ⁴ Bioinquiry, 3rd edition, Pruitt and Underwood. Wiley. 2006.
- ⁵ Cell and Molecular Biology, 5th edition, Gerald Karp. Wiley. 2008.
- ⁶ "BioMEMS applied to the development of cell-based bioassay systems", Brennan, Colin J.; Domansky, Karel; Kurzawski, Petra; Griffith, Linda G.
- ⁷ "Micro- and Nanotechnology for Biomedical and Environmental Applications". Proc. SPIE Vol. 3912, p. 76-87. 2000.
- ⁸ Microfluidics, BioMEMS, and Medical Microsystems II. Edited by Woias, Peter; Papautsky, Ian. Proceedings of the SPIE, Volume 5345, pp. 17-25. 2003.
- ⁹ "Advances in on-chip photodetection for applications in miniaturized genetic analysis systems", Namasivayam, Vijay; Lin, Rongsheng; Johnson, Brian; Brahmasandra, Sundaresh; Razzacki, Zafar; Burke, David T.; Burns, Mark A. *Journal of Micromechanics and Microengineering*, Volume 14, Issue 1, pp. 81-90. 2004.
- ¹⁰ "Cell Culture". Arshad Chaudry. The Science Creative Quarterly. Issue 3. August 2004.
- ¹¹ Phenotype MicroArray TM can test thousands of cell properties simultaneously. Tim Mullane. Biology.com. EurekaAlert! June 25, 2001.

- http://www.eurekalert.org/pub_releases/2001-06/BI-PMct-0406101.php
- ¹² “Living Cell Microarrays: An Overview of Concepts”. Rebecca Johczyk. Microarrays (Basel). 2016 Jun;5(2): 11. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5003487/>
- ¹³ “Measuring Physical Properties of Neuronal and Glial Cells with Resonant Microsensors”. Corbin, Millet, Keller, King, and Bashir. University of Illinois. Analytical Chemistry 2014, 86, 4864-4872. http://libna.mntl.illinois.edu/pdf/publications/174_corbin.pdf

Related SCME Learning Modules

- BioMEMS Applications
- DNA Overview
- DNA to Protein Overview
- Biomolecular Applications in BioMEMS

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