Microbial Metabolism and Energetics

MCB 6417 (1 credit)

Sections 7138 and 1G63

Fall 2023

Instructor

Julie A. Maupin-Furlow, PhD. twitter - @Maupin_Furlow

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Preferred method for communication regarding the course is by email.

Please resolve technical issues by contacting the UF helpdesk (http://helpdesk.ufl.edu; (352) 392-HELP (4357); *helpdesk*@ufl.edu · HUB 132).

Delivery Method/Meeting Time

Fall 2023 semester: August 24 -October 13

All assignments, question/answer sessions, and other materials will be accessible online through Canvas, enabling asynchronous learning. This policy ensures that all meetings and class resources are conveniently available on the internet, allowing you to learn at your own pace and within the designated class deadlines.

For students in Gainesville who prefer in-person interactions, there is a designated meeting space available. The conference room 1054, located in the Microbiology and Cell Science building at 981, has been reserved specifically for this purpose. You can gather in this room on Tuesdays and Thursdays from 8-10:30 am EST to engage in discussions related to class materials, group presentations, and arrange meetings with the instructor, providing a comfortable and convenient setting for collaborative learning.

Students will have 15 hours of contact time (plus ~ 30 hours of preparation) associated with this 1 credit course.

Credits - 1

Course Description

MCB6417. Microbial Metabolism and Energetics. Credits: 1. Principles of energy and biosynthetic metabolisms will be examined in aerobic and anaerobic microorganisms. Current biotechnology practices that incorporate these principles will also be discussed.

Course Objectives/Goals/Learning Outcomes

The course aims to achieve the following objectives:

- To foster an understanding of the concepts and skills necessary to analyze and assess research pertaining to microbial metabolism and bioenergetics in a critical manner.
- To gain an understanding of the positive and negative effects that microbes have on global nutrient cycles. This includes exploring how microbes contribute to the cycling of nutrients in a beneficial manner, as well as the potential negative consequences that can arise from microbial activities in nutrient cycles.
- To apply theories of microbial metabolism and bioenergetics to real-world challenges, such as the utilization of microorganisms to produce bioproducts, alter nutrient cycles, and other valuable applications.
- To actively engage in reviewing and providing feedback on peer projects, employing the acquired knowledge and skills to contribute to the learning process of fellow students.

Course Materials

All required course materials will be available online through the Canvas e-Learning site (http://elearning.ufl.edu/) or through the UF library system.

Course Assignments

Please note that all students will be graded individually on all assignments in this course. **For the group assignments, each student within the group will be evaluated individually and independently of their group members**. As a result, students in the same group may not necessarily receive identical grades. To ensure impartial assessment by the instructor, students are requested to initial each slide they prepare and present. Additionally, it is advised for each student to introduce themselves before speaking.

Each group presentation should be ~**15 min total (estimate ~1 min per slide)**.

The group topics will revolve around microbial metabolism and bioenergetics, encompassing areas such as novel metabolic pathways, life's adaptation to extreme energy limitation, fundamental forms of energy conservation, and speculation on the bioenergetics of life's origins. The instructor will divide the class into groups, with assigned members whose composition may differ between groups A and B, to promote the generation of fresh ideas.

Group A oral report (100 points)**:** Group A presentations will focus on a single journal article. The group presentation should address the points listed on Canvas under assignments. See UF canvas (tabs within "people" section) to find your group number. Once you find this group number, go to **Appendix A** to find the assigned journal article.

Scientific questions to Group A peers (25 points). This is an individual assignment focused on enhancing scientific discussion of the Group A oral reports. Watch **five** Group A oral reports of your peer groups (not your own group presentation). Develop a thoughtful scientific question for each of the peer Group A oral reports. Read the article under discussion if you are confused by the presentation and need more background to formulate your question. Post your questions to each peer Group A in the "Discussion" section of the course on Canvas. In addition, assemble and upload the questions as a single word document to the assignment section of the course on Canvas for the instructor to review and grade.

Group A answers to scientific questions (25 points). This is a group assignment but all individuals within the group are expected to answer questions asked by their peers within the discussion section of Canvas. To monitor this activity, please assemble the questions asked by your peers and equally divide the load. Once the questions have been answered on the discussion panel, choose a group leader to assemble the questions and answers into a Word document. Initial each group member's answer. Upload this document to the Canvas assignment section of the course.

Group B oral report (100 points)**:** Group B oral reports are presentations focused on a topic related to microbial metabolism and energetics. In this group assignment, students are expected to perform a literature review related to the topic of discussion and synthesize the material into a comprehensive presentation. See UF canvas (tabs within "people" section) to find your group number. Once you find this group number, go to **Appendix B** to find your group topic. A reference list is provided in **Appendix B** for each topic to assist group members in getting started on the literature review and preparing the group presentation. The reference list is not meant to be comprehensive. Students are encouraged to find additional literature related to the topic of discussion. Students are expected to critically evaluate the literature and gain a deep understanding of the metabolic process under discussion prior to preparing the oral presentation. Students should clearly explain the topic in a manner that is scientifically accurate using their own words – do not plagiarize. To add excitement to the oral report – please take the time to discover what aspects of the topic may be on the cutting edge of new knowledge in the field.

Scientific questions to Group B peers (25 points). See related assignment instructions for asking scientific questions of Group A peers.

Group B answers to scientific questions (25 points). See related assignment for answering scientific questions of Group A peers.

Plagiarism: Please note that plagiarism is against the UF honor code (for details see https://www.dso.ufl.edu/sccr/process/student-conduct-honor-code/) (online modules are also available to assist you with making ethical decisions regarding plagiarism and other codes of conduct at https://www.dso.ufl.edu/sccr/seminars-modules/).

"(a) Plagiarism. A student shall not represent as the student's own work all or any portion of the work of another. Plagiarism includes but is not limited to:

1. Quoting oral or written materials including but not limited to those found on the internet, whether published or unpublished, without proper attribution."

You **must use your own words** to communicate oral and written materials presented in the oral reports, scientific evaluations, and summaries of this course.

Weekly Course Schedule

Schedule – Fall 2023

Week 1
R 08/24 Meet the Instructor
Introduction to the course

Week 2
T 08/29 Preparation of Group A oral report
R 08/31 Preparation of Group A oral report

Week 2
M 09/04 Holiday – Labor Day

T 09/05 Deadline for Group A oral report
R 09/07 Watch five Group A oral reports and post scientific questions

Week 3
T 09/12 Deadline for Scientific questions to Group A peers
R 09/14 Deadline for Group A answers to scientific questions

Week 4
T 09/19 Preparation of Group B oral report
R 09/21 Preparation of Group B oral report

Week 5
T 09/26 Preparation of Group B oral report
R 09/28 Deadline for submission of Group B oral report

Week 6
T 10/03 Watch five Group B oral reports and post scientific questions
R 10/05 Deadline for Scientific questions to Group B peers
F 10/06 UF Homecoming

Week 6
T 10/10 [catch up from homecoming]
R 10/12 Deadline for Group B answers to scientific questions

Upload all material onto the Canvas Course Website

GENERAL REFERENCE TEXTBOOK (RECOMMENDED):

White, D. 2006. *The Physiology and Biochemistry of Prokaryotes*. Third Edition. Oxford University Press, New York, NY. ISBN 0-19-530168-4.

[Exam Dates/Calendar/Critical dates and deadlines]

Deadlines
T 09/05 Deadline for Group A oral report
T 09/12 Deadline for Scientific questions to Group A peers
R 09/14 Deadline for Group A answers to scientific questions
R 09/28 Deadline for submission of Group B oral report
R 10/05 Deadline for Scientific questions to Group B peers
R 10/12 Deadline for Group B answers to scientific questions

Evaluation of Learning/Grades

MCB 6417 learning will be evaluated based on the following criteria:

100 points	Group A oral report - present on an assigned journal article
25 points	Scientific questions to Group A peers
25 points	Group A answers to scientific questions
100 points	Group B oral report - present on multiple journal articles synthesized into a cohesive assigned metabolic topic.
25 points	Scientific questions to Group B peers
25 points	Group B answers to scientific questions
300 points total	

[Materials and Supplies Fees]

There are no additional fees for this course.

Grading Policy

Final grades will be based on the following performance standard:

95 - 100 %	= A
90 - 94 %	= A-
87 - 89 %	= B+
84 - 86 %	= B
80 - 83 %	= B-
77 - 79 %	= C+
74 - 76 %	= C
70 - 73 %	= C-
60 - 69 %	= D
Less than 60 %	= E

More information on grades and grading policies is here:
https://catalog.ufl.edu/ugrad/current/regulations/info/grades.aspx

Class Attendance and Make-Up Policy

As an online class, this course does not have a designated meeting time. However, it is important to note that class deadlines must be adhered to. Furthermore, collaboration with peers to coordinate and prepare group presentations will require mutually agreed-upon meeting times as per the course requirements.

Make-up policies are according to UF guidelines (https://catalog.ufl.edu/ugrad/current/regulations/info/attendance.aspx) and require appropriate documentation. If a student is unable to complete classwork due to circumstances like illness, serious family emergencies, military obligations, jury duty, or immediate family bereavement, they must communicate the need for make-up by submitting formal signed documentation. It is crucial to notify the instructor in advance of the missed exam or assignment and provide appropriate documentation for the absence. Contacting the instructor in a timely manner allows for scheduling an alternative time to complete the missed classwork.

Students Requiring Accommodations

Students with disabilities requesting accommodations should first register with the Disability Resource Center (352-392-8565, www.dso.ufl.edu/drc/) by providing appropriate documentation. Once registered, students will receive an accommodation letter which must be presented to the instructor when requesting accommodation. Students with disabilities should follow this procedure as early as possible in the semester.

Campus Resources

Resources are available on campus for students having personal problems or lacking clear career and academic goals, which interfere with their academic performance. These resources include:

Health and Wellness

- U Matter, We Care: If you or a friend is in distress, please contact umatter@ufl.edu or 352 392-1575 so that a team member can reach out to the student.
- Counseling and Wellness Center: http://www.counseling.ufl.edu/cwc/Default.aspx, 392-1575;
- Sexual Assault Recovery Services (SARS) at the Student Health Care Center, 392-1161.
- For emergencies call: University Police Department, 392-1111 (or 9-1-1 for emergencies). http://www.police.ufl.edu/

Academic Resources

- E-learning technical support, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.
- Career Resource Center, Reitz Union, 392-1601. Career assistance and counseling. http://www.crc.ufl.edu/
- Library Support, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.
- Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. http://teachingcenter.ufl.edu/
- Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers. http://writing.ufl.edu/writing-studio/

Course Evaluation

"Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/."

Class demeanor

Students are required to actively participate in class and maintain a respectful attitude towards both the instructor and their peers. It is important to show respect for the opinions of others during discussions and keep conversations that do not contribute to the topic at hand to a minimum, or avoid them altogether.

Netiquette guide for online courses

It is important to recognize that the online classroom is in fact a classroom, and certain behaviors are expected when you communicate with both your peers and your instructors. These guidelines for online behavior and interaction are known as netiquette.
http://teach.ufl.edu/wp-content/uploads/2012/08/NetiquetteGuideforOnlineCourses.pdf

University Honesty Policy

UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://www.dso.ufl.edu/sccr/process/student-conduct-honor-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Software Use

All faculty, staff and students of the university are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against university policies and rules, disciplinary action will be taken as appropriate.

Microsoft Office 365 Software is free for UF students

http://www.it.ufl.edu/gatorcloud/free-office-365-downloads/

Other free software is available at:

http://www.software.ufl.edu/

To check for availability of the media and technical requirements, contact the UF Computing Help Desk at (352)392-HELP(4357).

University of Florida Complaints Policy and Student Complaint Process

Most problems, questions and concerns about the course will be resolved by professionally communicating with the instructor or the TAs.

The University of Florida believes strongly in the ability of students to express concerns regarding their experiences at the University. The University encourages its students who wish to file a written complaint to submit that complaint directly to the department that manages that policy.

If a problem really cannot be resolved by communicating with the instructor or the TAs you can contact

- Residential Course: https://www.dso.ufl.edu/documents/UF_Complaints_policy.pdf.
- Online Course: http://www.distance.ufl.edu/student-complaint-process.

University of Florida U Matter

Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

UF In Class Recording

Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor. A “class lecture” is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without the permission of the instructor is prohibited. To “publish” means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third-party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

Course Syllabus Policy: Use of Artificial Intelligence

1. Ethical Use of AI:

1.1. Students are expected to adhere to ethical guidelines when using AI tools and resources. This includes respecting privacy, security, and confidentiality of data, as well as ensuring fairness, transparency, and accountability in their AI applications.

1.2. Students should consider the potential biases and implications of their AI models and make efforts to mitigate any discriminatory or harmful effects.

1.3. Any use of AI for illegal or unethical purposes is strictly prohibited and may result in academic penalties.

2. Data Collection and Usage:

2.1. Students should obtain and use datasets in compliance with applicable legal and ethical standards. They should ensure that they have proper authorization, consent, or rights to use the data.

2.2. Students should handle personal or sensitive data responsibly and take appropriate measures to protect the privacy and security of such data.

3. AI Tools and Libraries:

3.1. Students are encouraged to explore and utilize a variety of AI tools and libraries, such as TensorFlow, PyTorch, scikit-learn, and others, to enhance their understanding and practical skills.
3.2. When using AI tools, students should ensure that they comply with the respective licenses and terms of use set by the tool developers.
3.3. Students should properly attribute any code or resources used from external sources, including AI libraries, frameworks, or pre-trained models.

4. Academic Integrity:
4.1. Students should uphold academic integrity at all times. Plagiarism, cheating, or any form of dishonesty is strictly prohibited.
4.2. If students use existing AI models, algorithms, or code in their projects, they should clearly acknowledge the source and provide appropriate citations.

5. Collaboration:
5.1. Collaboration among students is encouraged, as it fosters a collaborative learning environment. However, students should submit their own original work, and any collaborative effort should be appropriately acknowledged.
5.2. In group projects, each team member is responsible for contributing to the project's development and should be able to demonstrate their individual understanding of the concepts covered in the course.

6. Responsible AI Deployment:
6.1. Students should consider the broader societal impact and implications of AI applications. They should be mindful of the potential consequences, biases, and risks associated with AI deployment.
6.2. Throughout the course, students will engage in discussions on responsible AI practices, and they are expected to critically analyze and reflect on the ethical, legal, and social implications of AI.

Appendix A

Group A Oral Report Supplemental Material

Below please find a list of the papers for the group A oral reports.

Group A1
Zhou Y, Wei Y, Jiang L, Jiao X, Zhang Y. Anaerobic phloroglucinol degradation by *Clostridium scatologenes*. *mBio*. 2023 Jun 21:e0109923. doi: 10.1128/mbio.01099-23. PMID: 37341492.

Group A2
Paerl RW, Curtis NP, Bittner MJ, Cohn MR, Gifford SM, Bannon CC, Rowland E, Bertrand EM. Use and detection of a vitamin B1 degradation product yields new views of the marine B1 cycle and plankton metabolite exchange. *mBio*. 2023 Jun 28:e0006123. doi: 10.1128/mbio.00061-23. PMID: 37377416.

Group A3
Lu KJ, Chang CW, Wang CH, Chen FY, Huang IY, Huang PH, Yang CH, Wu HY, Wu WJ, Hsu KC, Ho MC, Tsai MD, Liao JC. An ATP-sensitive phosphoketolase regulates carbon fixation in cyanobacteria. *Nat Metab*. 2023 Jun 22. doi: 10.1038/s42255-023-00831-w. PMID: 37349485.

Group A4
Zhao, W., Zhong, B., Zheng, L. et al. Proteome-wide 3D structure prediction provides insights into the ancestral metabolism of ancient archaea and bacteria. *Nat Commun* 13, 7861 (2022). https://doi.org/10.1038/s41467-022-35523-8

Group A5
Guan, X., Erşan, S., Hu, X. et al. Maximizing light-driven CO_2 and N_2 fixation efficiency in quantum dot–bacteria hybrids. *Nat Catal* 5, 1019–1029 (2022). https://doi.org/10.1038/s41929-022-00867-3

Group A6
Jespersen M, Wagner T. Assimilatory sulfate reduction in the marine methanogen *Methanothermococcus thermolithotrophicus*. *Nat Microbiol*. 2023. doi: 10.1038/s41564-023-01398-8. PMID: 37277534.

Group A7
McIlroy, S.J., Leu, A.O., Zhang, X. et al. Anaerobic methanotroph '*Candidatus* Methanoperedens nitroreducens' has a pleomorphic life cycle. *Nat Microbiol* 8, 321–331 (2023). https://doi.org/10.1038/s41564-022-01292-9

Group A8
Wang, T., Shen, P., He, Y. et al. Spatial transcriptome uncovers rich coordination of metabolism in *E. coli* K12 biofilm. *Nat Chem Biol* (2023). https://doi.org/10.1038/s41589-023-01282-w

Other articles in the news which may be of general interest to the class:

Dama, A.C., Kim, K.S., Leyva, D.M. et al. BacterAI maps microbial metabolism without prior knowledge. *Nat Microbiol* 8, 1018–1025 (2023). https://doi.org/10.1038/s41564-023-01376-0

Appendix B

Group B Oral Report Supplemental Material

Below please find a list of the group topics. A reference list is included to help get you started in understanding the topic of your presentation. Students do not need to cover every paper on the list in the presentation and are encouraged to find additional literature related to the topic of discussion. Do not assign paper 1 to student 1 etc., as the presentation will be unorganized and will have redundant overlap. Students are expected to critically evaluate the literature chosen for the presentation and to gain a deep understanding of the metabolic process under discussion prior to preparing the oral presentation.

Please be sure to discuss the group topic as it relates to the basic mechanisms of <u>microbial</u> metabolism and bioenergetics. The basic mechanisms of systems of higher multicellular organisms (*e.g.,* plants and humans) can be used for comparison to the microbial systems under discussion. However, microbial systems should be the central focus of the report. Discussion of the microbial systems in terms of biotechnology applications, bioremediation, human health, and other areas of general interest is encouraged to relate the material to the auidence. **References for appendix B are cited below in parenthesis and listed at the end of the doument in numerical order.** The detailed reference information (author, title, journal, volume and page number) is listed at the end of the topics section. Remember, this list is not meant to be comprehensive. Students are encouraged to perform a literature review to become an expert on the group topic.

Group B1: Bioenergetics at the origins of life

- Bioenergetics and life's origins (1-3)
- Iron catalysis at the origin of life (4, 5)
- Remnants of an ancient metabolism without phosphate (6, 7)
- Root of the archaeal tree: CO_2 reduced to acetate via the Wood-Ljungdahl pathway (8)
- Metals, electron bifurcation, CO_2 reduction and water in biochemical evolution (9-11)

Group B2. Asgard archaea: cell structure and metabolism

- Diversity, function, and evolutionary implications in microbiomes (12)
- Metabolic symbiosis with hydrogen-scavenging microbes (13, 14)
- Evidence for homoacetogenesis (15)

Group B3. Flavin-based electron bifurcation (FBEB): a new form of energy conservation

- FBEB couples exergonic and endergonic oxidation-reduction reactions (16)
- Global organization of the FBEB enzymes (17)
- Historical perspective of FBEB (18)

Group B4. Homoacetogens and their CO_2-fixation strategies

- Overcoming energetic barriers in acetogenic C1 conversion (19)
- Strategies used by homoacetogens (20)
- Competition with methanogens (21)

Group B5: Aceticlastic methanogenesis

- Three major pathways of methanogenesis: aceticlastic, hydrogenotrophic and methylotrophic reviewed (22, 23) - stay focused on your group topic
- Acetotrophic methanogenesis (24)
- *Methanosarcina acetivorans* as a model system (25)

Group B6: Hydrogenotrophic and methylotrophic methanogenesis

- Three major pathways of methanogenesis: aceticlastic, hydrogenotrophic and methylotrophic reviewed (22, 23) - stay focused on your group topic
- Structural insight and basic mechanism of pathways (26)
- *Methanococcus maripaludis* as a hydrogenotrophic and methylotrophic methanogen and its potential applications (27)

Group B7: Aerobic methanotrophs

- Reference (28) provides an overview of all types of methanotrophs. For this group be sure to focus on the aerobic methanotrophs.
- Biochemistry of aerobic biological methane oxidation (29)
- Metals and aerobic methanotrophy (30)
- Use for production of high value compounds (31)

Group B8: Metal-dependent anaerobic oxidation of methane

- Reference (28) provides an overview of all types of methanotrophs. For this group be sure to focus on the metal-dependent anaerobic oxidation of methane
- Metal-dependent anaerobic oxidation of methane (32)

Group B9: Reverse methanogenesis and respiration in methanotrophic archaea

- Reference (28) provides an overview of all types of methanotrophs. For this group be sure to focus on reverse methanogenesis and respiration in methanotrophic archaea.
- Reverse methanogenesis and respiration in methanotrophic archaea (33)

Group B10: Hydrogenases and hydrogen production

- Hydrogen gas-evolving membrane-bound hydrogenases (34)
- Overview of [FeFe] hydrogenases (35, 36)
- Hydrogenase-dependent chemiosmotic mechanism (37)
- Microbes as factories for hydrogen production (38, 39)
- Thermophiles and biohydrogen production (40)

Group B11: Microbial interspecies electron transfer

- Microbial syntrophy (41, 42)
- Interspecies electron transfer (43-48)
- Protein nanowires (49)
- Biotechnology applications (50-53)

Group B12: Extracellular electron transfer (EET) mechanisms

- Highlight (54)
- EET between microbes and minerals (55)
- Flavin-based EET mechanism (56)
- EET mechanisms proposed for methanogens (57, 58)
- Green chemistry uses (59)

Group B13: Ammonia and ammonium oxidizing microorganisms

- Microbial N-cycle overview (60) (be sure to focus on ammonia oxidation)
- Overview (61)
- Complete ammonia oxidizers (comammox) (62-70)
- Ammonia oxidizing archaea (AOA) (71-76)
- Ammonia oxidizing bacteria (AOB) – see overview
- Anaerobic ammonium oxidation (anammox) (77)
- Biotech applications (78, 79)

References for Appendix B

1. Martin WF, Sousa FL, Lane N. 2014. Evolution. Energy at life's origin. Science 344:1092-3.
2. Lane N. 2017. Proton gradients at the origin of life. Bioessays 39.
3. Jackson JB. 2016. Natural pH gradients in hydrothermal alkali vents were unlikely to have played a role in the origin of life. J Mol Evol 83:1-11.
4. Camprubi E, Jordan SF, Vasiliadou R, Lane N. 2017. Iron catalysis at the origin of life. IUBMB Life 69:373-381.
5. Martin WF. 2020. Older than genes: The acetyl CoA pathway and origins. Front Microbiol 11:817.
6. Goldford JE, Hartman H, Smith TF, Segre D. 2017. Remnants of an ancient metabolism without phosphate. Cell 168:1126-1134 e9.
7. Martin WF, Thauer RK. 2017. Energy in ancient metabolism. Cell 168:953-955.
8. Williams TA, Szollosi GJ, Spang A, Foster PG, Heaps SE, Boussau B, Ettema TJG, Embley TM. 2017. Integrative modeling of gene and genome evolution roots the archaeal tree of life. Proc Natl Acad Sci U S A 114:E4602-E4611.
9. Sousa FL, Preiner M, Martin WF. 2018. Native metals, electron bifurcation, and CO. Curr Opin Microbiol 43:77-83.
10. Martin WF. 2019. Carbon-metal bonds: rare and primordial in metabolism. Trends Biochem Sci 44:807-818.
11. do Nascimento Vieira A, Kleinermanns K, Martin WF, Preiner M. 2020. The ambivalent role of water at the origins of life. FEBS Lett 594:2717-2733.
12. MacLeod F, Kindler GS, Wong HL, Chen R, Burns BP. 2019. Asgard archaea: Diversity, function, and evolutionary implications in a range of microbiomes. AIMS Microbiol 5:48-61.
13. López-García P, Moreira D. 2020. Cultured Asgard archaea shed light on eukaryogenesis. Cell 181:232-235.
14. López-García P, Moreira D. 2020. The Syntrophy hypothesis for the origin of eukaryotes revisited. Nat Microbiol 5:655-667.
15. Orsi WD, Vuillemin A, Rodriguez P, Coskun Ö, Gomez-Saez GV, Lavik G, Mohrholz V, Ferdelman TG. 2020. Metabolic activity analyses demonstrate that Lokiarchaeon exhibits homoacetogenesis in sulfidic marine sediments. Nat Microbiol 5:248-255.

16. Peters JW, Beratan DN, Bothner B, Dyer RB, Harwood CS, Heiden ZM, Hille R, Jones AK, King PW, Lu Y, Lubner CE, Minteer SD, Mulder DW, Raugei S, Schut GJ, Seefeldt LC, Tokmina-Lukaszewska M, Zadvornyy OA, Zhang P, Adams MW. 2018. A new era for electron bifurcation. Curr Opin Chem Biol 47:32-38.
17. Kayastha K, Vitt S, Buckel W, Ermler U. 2021. Flavins in the electron bifurcation process. Arch Biochem Biophys 701:108796.
18. Muller V, Chowdhury NP, Basen M. 2018. Electron bifurcation: a long-hidden energy-coupling mechanism. Annu Rev Microbiol 72:331-353.
19. Katsyv A, Müller V. 2020. Overcoming energetic barriers in acetogenic C1 conversion. Front Bioeng Biotechnol 8:621166.
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