George Whitesides

Keynote: Origin of Life

1
00:00:00,720 --> 00:00:11,299
[Music]

2
00:00:18,390 --> 00:00:13,680
so it's a great pleasure for me to be

3
00:00:22,920 --> 00:00:18,400
here I'm a representative of the group

4
00:00:25,529 --> 00:00:22,930
which is here a group originally started

5
00:00:28,470 --> 00:00:25,539
by demitasse a Salafis an astronomer and

6
00:00:31,050 --> 00:00:28,480
Jack szostak who is an RNA guy and then

7
00:00:34,770 --> 00:00:31,060
others have grown men and what I would

8
00:00:36,900 --> 00:00:34,780
say about us is that each one of us has

9
00:00:40,860 --> 00:00:36,910
strong opinions which happened to have

10
00:00:43,350 --> 00:00:40,870
almost no overlap and so I fight

11
00:00:46,440 --> 00:00:43,360
endlessly with these guys we get along

12
00:00:50,010 --> 00:00:46,450
very well but we don't actually know the

13
00:00:53,160 --> 00:00:50,020

answer and what is to me so exciting

14
00:00:58,920 --> 00:00:53,170
about this area is that much of science

15
00:01:01,590 --> 00:00:58,930
proceeds by discussions of development

16
00:01:04,979 --> 00:01:01,600
of a topic which is already in a sense

17
00:01:06,930 --> 00:01:04,989
understood and as Eric said it would be

18
00:01:09,359 --> 00:01:06,940
nice to put this on a footing where one

19
00:01:11,550 --> 00:01:09,369
can develop well-defined hypotheses and

20
00:01:14,070 --> 00:01:11,560
go forward we're not there yet

21
00:01:16,679 --> 00:01:14,080
so what I'm going to tell you is less

22
00:01:18,990 --> 00:01:16,689
about what I don't know and think needs

23
00:01:20,700 --> 00:01:19,000
to be known then about what I do know

24
00:01:26,010 --> 00:01:20,710
although I'll tell you some things that

25
00:01:29,999 --> 00:01:26,020
might be a start to what we do know so

26
00:01:32,850 --> 00:01:30,009
let me start with some broad questions

27
00:01:34,710 --> 00:01:32,860
since as the first speaker one gets to

28
00:01:39,590 --> 00:01:34,720
talk about things which have almost no

29
00:01:42,420 --> 00:01:39,600
substance here's one where do we start

30
00:01:44,670 --> 00:01:42,430
where did life come from I am a bottom

31
00:01:47,399 --> 00:01:44,680
up person I'm interested in how you go

32
00:01:49,710 --> 00:01:47,409
from whatever it is that fell in from

33
00:01:52,950 --> 00:01:49,720
space and was produced by geochemistry

34
00:01:55,499 --> 00:01:52,960
to the first primitive things that might

35
00:01:57,300 --> 00:01:55,509
have become cells what comes later is

36
00:01:58,980 --> 00:01:57,310
very interesting as well but I'm

37
00:02:01,889 --> 00:01:58,990
specifically interested in this question

38
00:02:07,020 --> 00:02:01,899

a second question

39
00:02:12,120 --> 00:02:07,030
and I'm not sure whether this is on am i

40
00:02:14,280 --> 00:02:12,130
can you hear from the back ok at the

41
00:02:18,390 --> 00:02:14,290
beginning we know that the planet was a

42
00:02:20,430 --> 00:02:18,400
real mess that was the end of the period

43
00:02:23,039 --> 00:02:20,440
of heavy bombardment there was all kinds

44
00:02:24,360 --> 00:02:23,049
of stuff going on you would think it was

45
00:02:26,309 --> 00:02:24,370
an ideally bad

46
00:02:29,100 --> 00:02:26,319
environment to create something that was

47
00:02:31,649 --> 00:02:29,110
delicate and organic and just hanging on

48
00:02:33,750 --> 00:02:31,659
to being organized how did that happen

49
00:02:36,149 --> 00:02:33,760
and I don't think that this process of

50
00:02:39,350 --> 00:02:36,159
going from a chaotic environment into an

51
00:02:41,520 --> 00:02:39,360
ordered cell as it all understood a

52
00:02:43,710 --> 00:02:41,530
third question which is really

53
00:02:46,680 --> 00:02:43,720
interesting from the point of view of

54
00:02:51,930 --> 00:02:46,690
trying to decide what we're doing is how

55
00:02:56,190 --> 00:02:51,940
do we think about life and the question

56
00:02:58,949 --> 00:02:56,200
about life in a sense is how do we know

57
00:03:00,809 --> 00:02:58,959
when we've succeeded if we study this

58
00:03:02,970 --> 00:03:00,819
area we're interested in the origin of

59
00:03:04,680 --> 00:03:02,980
life how do we know that we're there how

60
00:03:07,500 --> 00:03:04,690
do we know that we've got life what is

61
00:03:09,599 --> 00:03:07,510
what is the first thing that's alive not

62
00:03:12,030 --> 00:03:09,609
an easy question to answer I think and

63
00:03:13,920 --> 00:03:12,040

so that's an interesting one to consider

64
00:03:16,559 --> 00:03:13,930
and I have to say just to give you a

65
00:03:18,960 --> 00:03:16,569
sense that I think that it's a perfectly

66
00:03:22,800 --> 00:03:18,970
legitimate exercise to think about life

67
00:03:26,039 --> 00:03:22,810
as being a form of flame in which

68
00:03:28,349 --> 00:03:26,049
instead of generating heat from the

69
00:03:31,589 --> 00:03:28,359
combustion of methane and oxygen you

70
00:03:33,960 --> 00:03:31,599
generate you from the combustion of

71
00:03:38,129 --> 00:03:33,970
oxygen and glucose it's just a set of

72
00:03:40,500 --> 00:03:38,139
interesting chemical reactions or alive

73
00:03:42,720 --> 00:03:40,510
and not alive different that's an

74
00:03:44,069 --> 00:03:42,730
interesting question and one which is

75
00:03:46,229 --> 00:03:44,079
important if you're interested in the

76
00:03:48,270 --> 00:03:46,239
origins because life and death of the

77
00:03:50,159 --> 00:03:48,280
opposite sides of the same sandwich in a

78
00:03:52,920 --> 00:03:50,169
sense and you should be able to

79
00:03:55,319 --> 00:03:52,930
understand the two and then finally a

80
00:03:58,020 --> 00:03:55,329
question we will talk about and others

81
00:03:59,849 --> 00:03:58,030
will talk about which is the explosion

82
00:04:02,280 --> 00:03:59,859
of fascinating stuff that's going on in

83
00:04:04,680 --> 00:04:02,290
planetary astronomy if life is

84
00:04:06,089 --> 00:04:04,690
inevitable on any planet with water then

85
00:04:09,119 --> 00:04:06,099
there must be life everywhere at least

86
00:04:14,159 --> 00:04:09,129
sparkles of it and that changes our view

87
00:04:17,490 --> 00:04:14,169
of our place in the universe now let me

88
00:04:19,229 --> 00:04:17,500

give you a brief history this is going

89
00:04:20,939 --> 00:04:19,239
to if some of you are a professional

90
00:04:25,409 --> 00:04:20,949
organic chemist you should find this

91
00:04:29,430 --> 00:04:25,419
infuriating the I say organic chemistry

92
00:04:31,050 --> 00:04:29,440
primarily because life is largely at

93
00:04:32,610 --> 00:04:31,060
least in terms of mass and organic

94
00:04:34,589 --> 00:04:32,620
phenomenon in organic chemistry is

95
00:04:36,120 --> 00:04:34,599
important in physical chemistry is

96
00:04:37,920 --> 00:04:36,130
important in thinking about it and

97
00:04:40,650 --> 00:04:37,930
physics is important overwhelming

98
00:04:42,320 --> 00:04:40,660
in the overall arching thing but let me

99
00:04:44,909 --> 00:04:42,330
give you a history of organic chemistry

100
00:04:47,490 --> 00:04:44,919
it started by making complicated

101
00:04:50,370 --> 00:04:47,500
molecules first simple ones and complex

102
00:04:53,999 --> 00:04:50,380
ones and these molecules are trapped

103
00:04:55,860 --> 00:04:54,009
metastable States by which I mean that

104
00:04:58,680 --> 00:04:55,870
all of us at thermodynamic equilibrium

105
00:05:01,200 --> 00:04:58,690
would be co2 and water and nitrogen and

106
00:05:01,830 --> 00:05:01,210
- but we don't burn because we're

107
00:05:06,240 --> 00:05:01,840
trapped

108
00:05:08,999 --> 00:05:06,250
ok got it recently the last 20 years

109
00:05:10,820 --> 00:05:09,009
there's been a shift toward non-covalent

110
00:05:13,590 --> 00:05:10,830
chemistry and molecular self-assembly

111
00:05:15,180 --> 00:05:13,600
these are equilibrium structures the

112
00:05:17,760 --> 00:05:15,190
bonds that hold things together are

113
00:05:20,159 --> 00:05:17,770

weaker and they're interesting - you

114
00:05:21,990 --> 00:05:20,169
have a pretty good grip on these - and

115
00:05:24,659 --> 00:05:22,000
neither one of them is sufficient to

116
00:05:26,340 --> 00:05:24,669
explain the origin of life so what one

117
00:05:29,730 --> 00:05:26,350
has to do is to go to the next step

118
00:05:31,860 --> 00:05:29,740
which is dynamic systems and chemistry

119
00:05:33,779 --> 00:05:31,870
when you're out of equilibrium when the

120
00:05:36,120 --> 00:05:33,789
phenomena that you're looking at require

121
00:05:37,890 --> 00:05:36,130
the flow of energy and the dissipation

122
00:05:39,930 --> 00:05:37,900
of energy through the system that you're

123
00:05:41,760 --> 00:05:39,940
looking at and what's interesting is the

124
00:05:44,810 --> 00:05:41,770
result of dissipation of energy is

125
00:05:47,969 --> 00:05:44,820
something we understand very very poorly

126
00:05:51,180 --> 00:05:47,979
so a wonderful area from that point of

127
00:05:52,770 --> 00:05:51,190
view and why is it that chemistry hasn't

128
00:05:54,810 --> 00:05:52,780
gone this route and I'll give you a

129
00:05:55,620 --> 00:05:54,820
sense here's the result of complex

130
00:05:58,920 --> 00:05:55,630
chemistry

131
00:06:02,189 --> 00:05:58,930
here's self-assembly and my mother who

132
00:06:04,230 --> 00:06:02,199
was a wise and difficult woman used to

133
00:06:05,939 --> 00:06:04,240
say that you know why haven't people

134
00:06:07,409 --> 00:06:05,949
gone on to the other thing and her view

135
00:06:11,490 --> 00:06:07,419
was you could never change anyone's mind

136
00:06:13,469 --> 00:06:11,500
you just wait for them to die this was

137
00:06:14,700 --> 00:06:13,479
said into some way more fashionable way

138
00:06:17,969 --> 00:06:14,710

by mr. Pauli

139
00:06:21,210 --> 00:06:17,979
whose science progresses one funeral at

140
00:06:23,159 --> 00:06:21,220
a time so we're waiting right now for

141
00:06:25,140 --> 00:06:23,169
the people who do complex organic

142
00:06:30,810 --> 00:06:25,150
synthesis and molecular self-assembly to

143
00:06:33,810 --> 00:06:30,820
reach my age and die themes what came

144
00:06:36,600 --> 00:06:33,820
before and here we begin to get into

145
00:06:39,899 --> 00:06:36,610
some of the interesting subjects one of

146
00:06:42,540 --> 00:06:39,909
them is as I'll come back and discuss in

147
00:06:44,600 --> 00:06:42,550
a bit there are a number of different

148
00:06:47,969 --> 00:06:44,610
ideologies in this area not

149
00:06:50,010 --> 00:06:47,979
overwhelmingly connected one of them

150
00:06:51,690 --> 00:06:50,020
that's been very very successful has

151
00:06:54,030 --> 00:06:51,700
been work that

152
00:06:56,640 --> 00:06:54,040
arted really was I guess Orgel but was

153
00:06:59,430 --> 00:06:56,650
we're going and people of that sort Yuri

154
00:07:01,950 --> 00:06:59,440
Miller but reached a very high point

155
00:07:05,220 --> 00:07:01,960
with with Alberta and Moser and then

156
00:07:07,530 --> 00:07:05,230
with Jack szostak continuing which is to

157
00:07:11,190 --> 00:07:07,540
start with simple molecules

158
00:07:14,520 --> 00:07:11,200
HCN methane ammonia carbon monoxide

159
00:07:16,800 --> 00:07:14,530
carbon dioxide so on and do prebiotic

160
00:07:18,930 --> 00:07:16,810
chemistry that is to show that plausible

161
00:07:22,140 --> 00:07:18,940
reactions starting with simple materials

162
00:07:26,460 --> 00:07:22,150
can make the kinds of molecules that you

163
00:07:28,380 --> 00:07:26,470

find in life work very well the question

164
00:07:31,170 --> 00:07:28,390
of how relevant it is is a question

165
00:07:32,640 --> 00:07:31,180
which you can discuss because much of

166
00:07:36,090 --> 00:07:32,650
this chemistry all of this chemistry

167
00:07:39,270 --> 00:07:36,100
goes on in organic chemistry conditions

168
00:07:42,000 --> 00:07:39,280
in flasks with good Swiss postdocs

169
00:07:43,890 --> 00:07:42,010
running the reaction and that doesn't

170
00:07:48,570 --> 00:07:43,900
detract from the chemistry it just

171
00:07:50,790 --> 00:07:48,580
raises questions about plausibility what

172
00:07:53,310 --> 00:07:50,800
had to happen at that point is that

173
00:07:55,950 --> 00:07:53,320
chemistry somehow organized itself into

174
00:07:58,080 --> 00:07:55,960
networks that is the beginnings of

175
00:08:00,090 --> 00:07:58,090
metabolism we don't know how that

176
00:08:04,020 --> 00:08:00,100
happened we do not know how that

177
00:08:08,820 --> 00:08:04,030
happened and that's a key point so their

178
00:08:11,070 --> 00:08:08,830
ideologies and one ideology is the

179
00:08:14,010 --> 00:08:11,080
ideology of organic chemists who make

180
00:08:15,870 --> 00:08:14,020
complex molecules and and John

181
00:08:18,000 --> 00:08:15,880
Sutherland is an expert at this and he

182
00:08:19,530 --> 00:08:18,010
does it fantastically well and then you

183
00:08:22,680 --> 00:08:19,540
assume that the rest take cares and

184
00:08:25,260 --> 00:08:22,690
takes care of itself a second ideology

185
00:08:27,600 --> 00:08:25,270
is the one that starts from the biology

186
00:08:30,360 --> 00:08:27,610
and works backwards my friend Jack

187
00:08:32,850 --> 00:08:30,370
szostak is big on this he says assume

188
00:08:35,430 --> 00:08:32,860

there with enough oceans and enough

189
00:08:39,830 --> 00:08:35,440
billions of years RNA spontaneously

190
00:08:43,350 --> 00:08:39,840
emerged well that makes it easier and

191
00:08:45,240 --> 00:08:43,360
the question of how you connect these to

192
00:08:48,510 --> 00:08:45,250
the molecules and the precursors is

193
00:08:52,140 --> 00:08:48,520
comes to this issue of the networks and

194
00:08:55,230 --> 00:08:52,150
so we have networks we have molecules we

195
00:08:59,160 --> 00:08:55,240
have precursors but there's some parts

196
00:09:01,860 --> 00:08:59,170
that are actually missing and by to give

197
00:09:05,460 --> 00:09:01,870
you a prejudice I by professional

198
00:09:08,010 --> 00:09:05,470
background and really someone who goes

199
00:09:10,290 --> 00:09:08,020
the steps of quantum mechanics to

200
00:09:13,200 --> 00:09:10,300
statistical mechanics to thermodynamics

201
00:09:16,440 --> 00:09:13,210
I think this is one of the great triads

202
00:09:17,640 --> 00:09:16,450
in natural science and one of the things

203
00:09:21,330 --> 00:09:17,650
that we're missing here

204
00:09:22,950 --> 00:09:21,340
is understanding not what could possibly

205
00:09:25,020 --> 00:09:22,960
have happened but what could

206
00:09:28,260 --> 00:09:25,030
statistically have happened what is

207
00:09:30,110 --> 00:09:28,270
actually plausible statistically if you

208
00:09:33,060 --> 00:09:30,120
have molecules and you put them together

209
00:09:36,510 --> 00:09:33,070
will they spy ever spontaneously form

210
00:09:39,060 --> 00:09:36,520
networks and I'll come back to that in a

211
00:09:41,100 --> 00:09:39,070
bit and then we go on with other things

212
00:09:44,220 --> 00:09:41,110
but eventually one has to get to this

213
00:09:46,800 --> 00:09:44,230

big trick of evolution which is

214
00:09:48,600 --> 00:09:46,810
molecular memory and expression and the

215
00:09:51,450 --> 00:09:48,610
two pieces that go along with it and the

216
00:09:53,520 --> 00:09:51,460
key element which is not well understood

217
00:09:56,250 --> 00:09:53,530
at all which is the emergence of

218
00:09:59,790 --> 00:09:56,260
enzymatic catalysis because networks in

219
00:10:06,510 --> 00:09:59,800
biology are really networks of catalysts

220
00:10:08,490 --> 00:10:06,520
not networks of molecules so then let me

221
00:10:10,950 --> 00:10:08,500
summarize this part of things this way

222
00:10:13,740 --> 00:10:10,960
there's the chemistry forward part this

223
00:10:16,010 --> 00:10:13,750
has gone extraordinarily well this has

224
00:10:18,750 --> 00:10:16,020
gone well in academic laboratories

225
00:10:20,970 --> 00:10:18,760
there's the backward way which starts

226
00:10:22,890 --> 00:10:20,980
with DNA RNA we all agree is an

227
00:10:25,530 --> 00:10:22,900
important component and comes from

228
00:10:28,050 --> 00:10:25,540
somewhere and what's missing is this

229
00:10:31,380 --> 00:10:28,060
part in between which is where the

230
00:10:33,930 --> 00:10:31,390
metabolism networks catalysis where did

231
00:10:37,040 --> 00:10:33,940
that come from and how can it possibly

232
00:10:41,040 --> 00:10:37,050
have happened and to be perfectly frank

233
00:10:43,770 --> 00:10:41,050
I'm a professor and professors have the

234
00:10:45,390 --> 00:10:43,780
skill of being able to take any subject

235
00:10:49,079 --> 00:10:45,400
and talk about it

236
00:10:51,990 --> 00:10:49,089
knowledgeably I have no clue I do not

237
00:10:57,079 --> 00:10:52,000
understand everything so it makes it a

238
00:10:59,430 --> 00:10:57,089

great problem I want to give you two

239
00:11:01,980 --> 00:10:59,440
pictures to think about these are very

240
00:11:06,000 --> 00:11:01,990
simple but they're actually pretty

241
00:11:08,220 --> 00:11:06,010
profound you all have seen this you take

242
00:11:11,370 --> 00:11:08,230
coffee you pour something into it it

243
00:11:15,150 --> 00:11:11,380
spontaneously mixes nothing to think

244
00:11:17,010 --> 00:11:15,160
about there or is there as you look at

245
00:11:18,840 --> 00:11:17,020
it the other way around and assume you

246
00:11:21,689 --> 00:11:18,850
go from left to right

247
00:11:23,429 --> 00:11:21,699
the answer here is well you're never

248
00:11:26,549 --> 00:11:23,439
gonna have a cup of coffee with mixed

249
00:11:31,259 --> 00:11:26,559
coffee and milk spontaneously spit out

250
00:11:35,249 --> 00:11:31,269
milk and form that we know that why is

251
00:11:39,689 --> 00:11:35,259
it and whenever you ask the question why

252
00:11:41,819 --> 00:11:39,699
you run into problems in science and you

253
00:11:45,929 --> 00:11:41,829
say first well that's not fair because

254
00:11:48,689 --> 00:11:45,939
what you're doing here is is something

255
00:11:52,379 --> 00:11:48,699
in which in this previous picture what

256
00:11:55,559 --> 00:11:52,389
happened was the coffee fell in the

257
00:11:58,049 --> 00:11:55,569
coffee fell in it mixed is it mixed

258
00:12:00,779 --> 00:11:58,059
something happened in tropically and

259
00:12:02,909 --> 00:12:00,789
there was heat generated from gravity

260
00:12:06,329 --> 00:12:02,919
and potential energy and you can't get

261
00:12:09,269 --> 00:12:06,339
those two back but you know my view

262
00:12:10,859 --> 00:12:09,279
would be ok that's fine it's this still

263
00:12:13,229 --> 00:12:10,869

isn't going to happen if I put it in

264
00:12:16,799 --> 00:12:13,239
boiling water so I've got lots of energy

265
00:12:19,109 --> 00:12:16,809
or EXOR radiated or whatever I've got

266
00:12:20,519 --> 00:12:19,119
lots of energy so it isn't the energy

267
00:12:24,599 --> 00:12:20,529
issue that's the important issue

268
00:12:27,029 --> 00:12:24,609
it's the entropy issue now there's

269
00:12:29,729 --> 00:12:27,039
always this question that is raised in

270
00:12:31,199 --> 00:12:29,739
discussions of quantum mechanics where

271
00:12:33,899 --> 00:12:31,209
if you talk to people about quantum

272
00:12:35,549 --> 00:12:33,909
mechanics and you say do you understand

273
00:12:37,199 --> 00:12:35,559
quantum mechanics and they say yes we

274
00:12:39,079 --> 00:12:37,209
understand quantum mechanics you know

275
00:12:41,519 --> 00:12:39,089
they don't understand quantum mechanics

276
00:12:43,679 --> 00:12:41,529
because quantum mechanics is understand

277
00:12:45,419 --> 00:12:43,689
not really understandable and the

278
00:12:47,269 --> 00:12:45,429
trouble with statistical mechanics is

279
00:12:50,129 --> 00:12:47,279
that although it's nothing more than

280
00:12:51,629 --> 00:12:50,139
throwing dice it's really hard to

281
00:12:55,799 --> 00:12:51,639
understand when you get the big numbers

282
00:12:59,129 --> 00:12:55,809
and so the question of why this doesn't

283
00:13:00,599 --> 00:12:59,139
happen is not the trivial thing that you

284
00:13:03,509 --> 00:13:00,609
might think it would be there's lots of

285
00:13:05,429 --> 00:13:03,519
energy around in principle but the

286
00:13:07,469 --> 00:13:05,439
mixing the question of what you do when

287
00:13:09,509 --> 00:13:07,479
you take 10 to the 23rd or something and

288
00:13:12,929 --> 00:13:09,519

mix it with 10 to the 22nd of something

289
00:13:15,599 --> 00:13:12,939
else is quite profound to think about in

290
00:13:17,939 --> 00:13:15,609
the context we're worrying about was you

291
00:13:20,249 --> 00:13:17,949
can make the molecules but they're in an

292
00:13:21,899 --> 00:13:20,259
ocean and so how do you put them

293
00:13:25,559 --> 00:13:21,909
together in such a fashion that they do

294
00:13:27,960 --> 00:13:25,569
something and this is the more important

295
00:13:30,539 --> 00:13:27,970
problem we know how to convert this into

296
00:13:32,560 --> 00:13:30,549
this and the question is do you know how

297
00:13:34,540 --> 00:13:32,570
to convert that into that

298
00:13:38,140 --> 00:13:34,550
because everything that's here is

299
00:13:38,830 --> 00:13:38,150
basically here and it's just in a

300
00:13:41,200 --> 00:13:38,840
different form

301
00:13:42,790 --> 00:13:41,210
it's a trivial question but it's not at

302
00:13:45,730 --> 00:13:42,800
all trivial and it's not just the

303
00:13:47,890 --> 00:13:45,740
question of chemical reactions it's not

304
00:13:50,740 --> 00:13:47,900
a question of RNA it's something else

305
00:13:52,840 --> 00:13:50,750
and there's something else to me is

306
00:13:56,500 --> 00:13:52,850
what's what we don't understand even

307
00:13:58,560 --> 00:13:56,510
conceptually now I want to ask you

308
00:14:01,060 --> 00:13:58,570
another question

309
00:14:05,770 --> 00:14:01,070
and this has to do with the subject that

310
00:14:07,720 --> 00:14:05,780
everyone here understands maybe I don't

311
00:14:10,660 --> 00:14:07,730
what everyone else probably does

312
00:14:14,170 --> 00:14:10,670
and that's self-assembly and with

313
00:14:17,050 --> 00:14:14,180

molecules we understand self-assembly

314
00:14:18,730 --> 00:14:17,060
pretty well well one has these two

315
00:14:20,710 --> 00:14:18,740
pieces of this sort they're going to

316
00:14:23,620 --> 00:14:20,720
self-assemble when do they self assemble

317
00:14:25,930 --> 00:14:23,630
you need to have two and only two things

318
00:14:28,810 --> 00:14:25,940
really you need to have an attractive

319
00:14:31,450 --> 00:14:28,820
force which brings them together this is

320
00:14:34,510 --> 00:14:31,460
distance this is energy they come closer

321
00:14:37,390 --> 00:14:34,520
together the energy goes down but then

322
00:14:39,430 --> 00:14:37,400
you also have to have a a repulsive

323
00:14:43,720 --> 00:14:39,440
force or energy which when they get

324
00:14:45,790 --> 00:14:43,730
close enough pushes them apart and if

325
00:14:48,460 --> 00:14:45,800
you have those two you add a repulsion

326
00:14:50,140 --> 00:14:48,470
and an attraction you get to something

327
00:14:52,180 --> 00:14:50,150
that looks like this and what that says

328
00:14:54,970 --> 00:14:52,190
is so long as there's thermal agitation

329
00:14:57,580 --> 00:14:54,980
the system will come together until it

330
00:14:59,320 --> 00:14:57,590
reaches this bottom here the agitation

331
00:15:01,180 --> 00:14:59,330
has to be sufficiently small it doesn't

332
00:15:02,860 --> 00:15:01,190
get kicked out but so long as the

333
00:15:05,100 --> 00:15:02,870
agitation is small enough it'll come to

334
00:15:09,760 --> 00:15:05,110
rest down here and that's self-assembly

335
00:15:12,910 --> 00:15:09,770
god it happens all over but how do

336
00:15:14,500 --> 00:15:12,920
reactions self assemble because that's

337
00:15:17,080 --> 00:15:14,510
what we have to talk about if we're

338
00:15:19,470 --> 00:15:17,090

going to talk about networks we know

339
00:15:21,970 --> 00:15:19,480
that their reactions that occur and

340
00:15:25,960 --> 00:15:21,980
somehow those reactions have to come

341
00:15:28,450 --> 00:15:25,970
together to give a network in which the

342
00:15:29,890 --> 00:15:28,460
reactions are talking to one another not

343
00:15:32,410 --> 00:15:29,900
the molecules talking to one another

344
00:15:36,220 --> 00:15:32,420
you're talking about the self-assembly

345
00:15:40,650 --> 00:15:36,230
of a non non material thing what does

346
00:15:45,660 --> 00:15:42,269
I want to give you just a couple of

347
00:15:48,420 --> 00:15:45,670
examples of background earnest to give

348
00:15:51,240 --> 00:15:48,430
you what at least bothers us or bothers

349
00:15:53,970 --> 00:15:51,250
me about the difficulty of that problem

350
00:15:56,519 --> 00:15:53,980
this is all familiar these are this is

351
00:15:58,050 --> 00:15:56,529
work from the 80s that we did and other

352
00:16:00,119 --> 00:15:58,060
people have worked on the same kind of

353
00:16:01,530 --> 00:16:00,129
thing that show that you can get all

354
00:16:03,869 --> 00:16:01,540
kinds of interesting molecular

355
00:16:06,929 --> 00:16:03,879
self-assembly by using hydrogen bonds of

356
00:16:10,439 --> 00:16:06,939
the sort that make DNA and RNA and other

357
00:16:12,840 --> 00:16:10,449
things proteins in some ways not a

358
00:16:15,420 --> 00:16:12,850
problem although I should point out it's

359
00:16:16,759 --> 00:16:15,430
a problem in other senses but I want to

360
00:16:19,889 --> 00:16:16,769
show you an example of dynamic

361
00:16:23,069 --> 00:16:19,899
self-assembly this is the simplest

362
00:16:25,889 --> 00:16:23,079
system that we can think of what one has

363
00:16:28,290 --> 00:16:25,899

here is simply droplets of air bubbles

364
00:16:31,470 --> 00:16:28,300
of air coming through a t-junction

365
00:16:33,509 --> 00:16:31,480
forming bubbles here and then the

366
00:16:36,420 --> 00:16:33,519
bubbles expand into a channel that looks

367
00:16:38,400 --> 00:16:36,430
like this and if you look at this these

368
00:16:41,699 --> 00:16:38,410
things come through and look how they

369
00:16:43,650 --> 00:16:41,709
self assemble stunning pattern the

370
00:16:45,749 --> 00:16:43,660
physical chemistry of this the physics

371
00:16:47,610 --> 00:16:45,759
that underlies it is extremely

372
00:16:49,259 --> 00:16:47,620
straightforward in principle in

373
00:16:52,530 --> 00:16:49,269
principle it's the navier-stokes

374
00:16:54,360 --> 00:16:52,540
equation but having said that would you

375
00:16:57,179 --> 00:16:54,370
have predicted what we have predicted

376
00:17:00,210 --> 00:16:57,189
that it does this can we explain it yeah

377
00:17:02,160 --> 00:17:00,220
sort of sort of you can explain it but

378
00:17:04,319 --> 00:17:02,170
it's still a surprise and this is so

379
00:17:05,460 --> 00:17:04,329
much simpler than what one is thinking

380
00:17:07,770 --> 00:17:05,470
about when one thinks about a

381
00:17:11,039 --> 00:17:07,780
dissipative system in life that it's

382
00:17:15,120 --> 00:17:11,049
almost not the same ballpark let me show

383
00:17:19,740 --> 00:17:15,130
you another example and I think I have

384
00:17:22,439 --> 00:17:19,750
to run this mechanically the this system

385
00:17:25,230 --> 00:17:22,449
is the blue beads are nothing but little

386
00:17:27,390 --> 00:17:25,240
nylon spheres and the white beads are

387
00:17:33,779 --> 00:17:27,400
nothing but little Teflon spheres and

388
00:17:36,840 --> 00:17:33,789

they're in a dish and we shake the dish

389
00:17:39,419 --> 00:17:36,850
and the fact that shaking is erratic is

390
00:17:42,419 --> 00:17:39,429
just non-sync between the camera and the

391
00:17:45,960 --> 00:17:42,429
dish and I want you to watch what

392
00:17:49,020 --> 00:17:45,970
happens and this is a true dissipative

393
00:17:50,549 --> 00:17:49,030
system you're putting in energy and you

394
00:17:53,580 --> 00:17:50,559
notice they sort of rattle around but

395
00:17:54,630 --> 00:17:53,590
you see sort of little parts of things

396
00:17:57,840 --> 00:17:54,640
beginning to organ

397
00:18:00,450 --> 00:17:57,850
and then pretty soon you find larger

398
00:18:05,070 --> 00:18:00,460
pieces of things beginning to organize

399
00:18:08,930 --> 00:18:05,080
better and then what you find is after a

400
00:18:12,960 --> 00:18:08,940
little while though thing crystallizes

401
00:18:14,490 --> 00:18:12,970
now what's happening there and after a

402
00:18:16,169 --> 00:18:14,500
while I won't go through at all but what

403
00:18:18,779 --> 00:18:16,179
happens after all this becomes basically

404
00:18:20,730 --> 00:18:18,789
a perfect crystal what's happening is a

405
00:18:23,850 --> 00:18:20,740
dissipative process in which is these

406
00:18:25,830 --> 00:18:23,860
beads shake the blue beads spontaneously

407
00:18:28,049 --> 00:18:25,840
trade ions with the surface in which

408
00:18:30,779 --> 00:18:28,059
they're resting tribal charging to

409
00:18:32,759 --> 00:18:30,789
become positively charged no negatively

410
00:18:34,440 --> 00:18:32,769
charged the white beads become

411
00:18:36,810 --> 00:18:34,450
positively charged by chemistry that's

412
00:18:38,279 --> 00:18:36,820
not understood at all really and then

413
00:18:41,850 --> 00:18:38,289

you get a two dimensional Coulomb B

414
00:18:44,460 --> 00:18:41,860
crystal again I put these up not because

415
00:18:46,529 --> 00:18:44,470
they're relevant to life but because we

416
00:18:50,159 --> 00:18:46,539
can barely understand this level of

417
00:18:53,399 --> 00:18:50,169
complexity all right

418
00:18:56,580 --> 00:18:53,409
so replace my little dish with shaking

419
00:18:59,399 --> 00:18:56,590
beads with this and it gets to be a

420
00:19:03,720 --> 00:18:59,409
harder problem and so there's lots to be

421
00:19:05,820 --> 00:19:03,730
studied here and a final puzzle in this

422
00:19:07,169 --> 00:19:05,830
introductory piece and this to me I

423
00:19:11,070 --> 00:19:07,179
think is one of the more interesting

424
00:19:16,350 --> 00:19:11,080
problems in all of science right now we

425
00:19:18,480 --> 00:19:16,360
know that a cell whatever it is is a

426
00:19:21,870 --> 00:19:18,490
collection of molecules and we know that

427
00:19:23,240 --> 00:19:21,880
a molecule is not alive everybody would

428
00:19:26,100 --> 00:19:23,250
agree with that

429
00:19:28,080 --> 00:19:26,110
we know that reactions between molecules

430
00:19:30,889 --> 00:19:28,090
are not alive I don't know how to talk

431
00:19:33,509 --> 00:19:30,899
about a reaction as being alive

432
00:19:36,480 --> 00:19:33,519
we know that cells are nothing more than

433
00:19:38,549 --> 00:19:36,490
molecules which are not alive reacting

434
00:19:42,509 --> 00:19:38,559
which is not alive and yet the

435
00:19:46,139 --> 00:19:42,519
collection is alive how did that happen

436
00:19:49,590 --> 00:19:46,149
what happened there and we don't know

437
00:19:53,310 --> 00:19:49,600
and by the way if you like extrapolating

438
00:19:55,860 --> 00:19:53,320

I would make the argument that thinking

439
00:19:59,539 --> 00:19:55,870
is nothing more than reactions of

440
00:20:02,940 --> 00:19:59,549
molecules which are not thinking in

441
00:20:06,330 --> 00:20:02,950
arrangements which are not thinking and

442
00:20:07,850 --> 00:20:06,340
so thought is the same thing and this is

443
00:20:10,039 --> 00:20:07,860
my sort of

444
00:20:11,600 --> 00:20:10,049
Schewel argument that says that a flame

445
00:20:13,400 --> 00:20:11,610
is after all nothing more than an

446
00:20:15,650 --> 00:20:13,410
organized structure which is doing

447
00:20:16,700 --> 00:20:15,660
something getting off heat light based

448
00:20:20,900 --> 00:20:16,710
on combustion

449
00:20:24,380 --> 00:20:20,910
if you reorganize a flame it becomes you

450
00:20:26,840 --> 00:20:24,390
and if you organize it a slightly more

451
00:20:29,900 --> 00:20:26,850
complicated way it becomes a flame that

452
00:20:33,230 --> 00:20:29,910
thinks which is you certainly not me I

453
00:20:35,150 --> 00:20:33,240
barely think so these questions are very

454
00:20:38,240 --> 00:20:35,160
very interesting in the sense we truly

455
00:20:41,210 --> 00:20:38,250
are at least I truly have no idea how to

456
00:20:44,810 --> 00:20:41,220
put this together this is not trivial

457
00:20:47,840 --> 00:20:44,820
science this is good science so let me

458
00:20:52,070 --> 00:20:47,850
go back to my question questions where

459
00:20:56,210 --> 00:20:52,080
did life start and are there other kinds

460
00:20:58,280 --> 00:20:56,220
and I haven't said anything so far that

461
00:20:59,450 --> 00:20:58,290
says you couldn't have life based on a

462
00:21:03,230 --> 00:20:59,460
lot of other different kinds of

463
00:21:06,590 --> 00:21:03,240

chemistry I have said so far that it's

464
00:21:08,390 --> 00:21:06,600
chemistry was the start deterministic or

465
00:21:11,090 --> 00:21:08,400
did it just happen by accident

466
00:21:12,590 --> 00:21:11,100
a very important question because we

467
00:21:14,810 --> 00:21:12,600
don't have any way right now of saying

468
00:21:17,090 --> 00:21:14,820
that maybe we are the one place in the

469
00:21:18,980 --> 00:21:17,100
universe in which it just happened that

470
00:21:23,690 --> 00:21:18,990
enough oceans with enough time produced

471
00:21:25,820 --> 00:21:23,700
a protocell but we don't know and this

472
00:21:28,220 --> 00:21:25,830
comes into statistics and probability

473
00:21:32,060 --> 00:21:28,230
which is an area that this field has

474
00:21:33,320 --> 00:21:32,070
resolutely ignored so far because it's

475
00:21:36,980 --> 00:21:33,330
an uncomfortable area

476
00:21:38,570 --> 00:21:36,990
how does dissipation allow chaos to come

477
00:21:42,860 --> 00:21:38,580
in and one of the interesting questions

478
00:21:45,470 --> 00:21:42,870
here was was it chaos or in dissipative

479
00:21:47,690 --> 00:21:45,480
systems is there a physics that we

480
00:21:49,669 --> 00:21:47,700
haven't really thought about is there

481
00:21:53,210 --> 00:21:49,679
something new a new principle here oh

482
00:21:55,280 --> 00:21:53,220
and I don't know what it is but that's

483
00:21:57,320 --> 00:21:55,290
what makes it interesting people didn't

484
00:21:59,450 --> 00:21:57,330
know about quantum mechanics in 1900

485
00:22:02,270 --> 00:21:59,460
there was just one or two little things

486
00:22:06,560 --> 00:22:02,280
that didn't fit that forced the

487
00:22:08,720 --> 00:22:06,570
invention of quantum mechanics are they

488
00:22:11,210 --> 00:22:08,730

separate alive and not alive is a flame

489
00:22:13,130 --> 00:22:11,220
alive is a city alive I happen to think

490
00:22:14,799 --> 00:22:13,140
that cities are alive but that's a

491
00:22:17,919 --> 00:22:14,809
different issue

492
00:22:20,150 --> 00:22:17,929
how similar was life then and now

493
00:22:21,680 --> 00:22:20,160
obvious question is thinking about and

494
00:22:25,730 --> 00:22:21,690
the interesting issue

495
00:22:28,999 --> 00:22:25,740
here is that we look I think all of us

496
00:22:31,490 --> 00:22:29,009
look at what we see in ourselves and say

497
00:22:34,009 --> 00:22:31,500
that that reflects in some way some

498
00:22:37,330 --> 00:22:34,019
trace of what was there at the beginning

499
00:22:39,619 --> 00:22:37,340
but maybe then was different in some way

500
00:22:41,119 --> 00:22:39,629
you say you're just waving your hands

501
00:22:42,649 --> 00:22:41,129
and that's absolutely true I'm waving my

502
00:22:45,379 --> 00:22:42,659
hands but you don't want to miss things

503
00:22:47,840 --> 00:22:45,389
because quantum mechanics to take an

504
00:22:49,519 --> 00:22:47,850
example did not come as an extension of

505
00:22:52,690 --> 00:22:49,529
Newtonian mechanics

506
00:22:58,820 --> 00:22:52,700
it was a fundamentally fresh start and

507
00:23:00,320 --> 00:22:58,830
are we missing the fresh start here is

508
00:23:02,869 --> 00:23:00,330
there more life than just the set of

509
00:23:06,830 --> 00:23:02,879
molecular precursors for example the

510
00:23:07,999 --> 00:23:06,840
flame and then I'm going to come back to

511
00:23:13,129 --> 00:23:08,009
this how do we know if we've been

512
00:23:16,639 --> 00:23:13,139
successful so we know that the business

513
00:23:19,399 --> 00:23:16,649

of life is to make more life that seems

514
00:23:22,519 --> 00:23:19,409
to be what goes on but it's easy to

515
00:23:26,990 --> 00:23:22,529
mistake one cell becoming two and to

516
00:23:30,200 --> 00:23:27,000
becoming four for this and what goes on

517
00:23:32,060 --> 00:23:30,210
the machinery inside we sort of

518
00:23:34,430 --> 00:23:32,070
understand this what we do not

519
00:23:37,220 --> 00:23:34,440
understand at all we don't even

520
00:23:38,899 --> 00:23:37,230
understand how this operates homeostasis

521
00:23:41,810 --> 00:23:38,909
in the cell is still pretty much a

522
00:23:43,999 --> 00:23:41,820
mystery in large part but if you ask

523
00:23:46,940 --> 00:23:44,009
where it came from we don't know so to

524
00:23:49,369 --> 00:23:46,950
me and this is my prejudice this is

525
00:23:52,009 --> 00:23:49,379
where the core of this problem is where

526
00:23:54,919 --> 00:23:52,019
did that come from how could it possibly

527
00:23:59,360 --> 00:23:54,929
have happened in the chaotic environment

528
00:24:01,850 --> 00:23:59,370
of the early Earth and I would put just

529
00:24:04,669 --> 00:24:01,860
one more final detailed point on this

530
00:24:09,789 --> 00:24:04,679
and Jack szostak and I have argue about

531
00:24:14,330 --> 00:24:09,799
this endlessly the wonderful thing about

532
00:24:16,430 --> 00:24:14,340
the DNA RNA kind of story and Jack makes

533
00:24:20,899 --> 00:24:16,440
a big point of this he says let's assume

534
00:24:23,720 --> 00:24:20,909
RNA okay we assume RNA and then RNA has

535
00:24:26,419 --> 00:24:23,730
the virtue that it is both the catalyst

536
00:24:30,019 --> 00:24:26,429
and something that looks like a memory

537
00:24:33,200 --> 00:24:30,029
molecule so RNA can do it all that's the

538
00:24:35,240 --> 00:24:33,210

basis of the RNA world story the

539
00:24:37,610 --> 00:24:35,250
difficulty with that is that our

540
00:24:40,550 --> 00:24:37,620
is actually not a very good catalyst it

541
00:24:42,890 --> 00:24:40,560
works for nucleotides and things like

542
00:24:45,110 --> 00:24:42,900
that and it's actually not a very good

543
00:24:47,630 --> 00:24:45,120
memory molecule so the fact that it

544
00:24:50,510 --> 00:24:47,640
resembles DNA and it certainly is a

545
00:24:51,890 --> 00:24:50,520
piece of the ribosome is all fine but

546
00:24:54,590 --> 00:24:51,900
then how do you get to something that

547
00:24:57,020 --> 00:24:54,600
looks like a primitive ribosome if you

548
00:24:59,600 --> 00:24:57,030
had no machinery for making proteins and

549
00:25:01,970 --> 00:24:59,610
no no no knowledge of where RNA came

550
00:25:04,730 --> 00:25:01,980
from then how do you get to a starting

551
00:25:11,420 --> 00:25:04,740
ribosome and it's these pieces that are

552
00:25:13,970 --> 00:25:11,430
missing so one of the things that we've

553
00:25:15,800 --> 00:25:13,980
been talking about in the group and it's

554
00:25:18,290 --> 00:25:15,810
a key part of what I'm going to say is

555
00:25:20,390 --> 00:25:18,300
that there may be ways of doing this

556
00:25:23,330 --> 00:25:20,400
chemistry of making proteins and making

557
00:25:24,830 --> 00:25:23,340
other things that are not based on the

558
00:25:28,930 --> 00:25:24,840
system that we have right now and there

559
00:25:31,720 --> 00:25:28,940
is one I think interesting kind of

560
00:25:34,730 --> 00:25:31,730
example which is non-ribosomal peptide

561
00:25:35,450 --> 00:25:34,740
synthesis this is two dudes the so

562
00:25:38,210 --> 00:25:35,460
called thio

563
00:25:42,080 --> 00:25:38,220

ester world in which instead of making

564
00:25:43,910 --> 00:25:42,090
fairly complex oligopeptides one by a

565
00:25:46,430 --> 00:25:43,920
ribosome what one does is to make them

566
00:25:48,770 --> 00:25:46,440
by another piece of machinery in which a

567
00:25:52,520 --> 00:25:48,780
series of thio esters react with one

568
00:25:54,980 --> 00:25:52,530
another and although in bacteria this

569
00:25:58,250 --> 00:25:54,990
machinery is pretty well organized in

570
00:25:59,690 --> 00:25:58,260
proteins in principle you could at least

571
00:26:01,870 --> 00:25:59,700
imagine that it might have been

572
00:26:05,180 --> 00:26:01,880
organized on other kinds of matrices and

573
00:26:07,070 --> 00:26:05,190
this might be a sort of step and

574
00:26:09,770 --> 00:26:07,080
although I'm not going to talk about

575
00:26:13,400 --> 00:26:09,780
this I am going to use thio esters and

576
00:26:16,160 --> 00:26:13,410
why and this is one of the things I

577
00:26:18,020 --> 00:26:16,170
think we can must want to look at thio

578
00:26:21,470 --> 00:26:18,030
esters are actually pretty remarkable

579
00:26:23,420 --> 00:26:21,480
this is a thioester and it has a very

580
00:26:26,750 --> 00:26:23,430
important characteristic which is that

581
00:26:32,000 --> 00:26:26,760
it will react with a thigh all that is

582
00:26:34,040 --> 00:26:32,010
are SH to do an interchange of this for

583
00:26:35,870 --> 00:26:34,050
this and hence of the products that come

584
00:26:39,230 --> 00:26:35,880
from this it will do that in

585
00:26:40,880 --> 00:26:39,240
quantitative yield why is that important

586
00:26:42,770 --> 00:26:40,890
and I think there are many arguments

587
00:26:45,650 --> 00:26:42,780
that say that reversibility of these

588
00:26:48,260 --> 00:26:45,660

reactions is important in generating the

589
00:26:49,190 --> 00:26:48,270
arrays which allow selection which allow

590
00:26:52,009 --> 00:26:49,200
optimization

591
00:26:55,220 --> 00:26:52,019
I mean this may not be true but I think

592
00:26:57,500 --> 00:26:55,230
that a key component to prebiotic

593
00:27:00,440 --> 00:26:57,510
evolution has to be reversibility and

594
00:27:03,080 --> 00:27:00,450
this is a remarkable reaction in that

595
00:27:06,080 --> 00:27:03,090
this functional group is beautifully

596
00:27:09,620 --> 00:27:06,090
reactive but unlike other activated

597
00:27:12,560 --> 00:27:09,630
esters it does not hydrolyze so it mean

598
00:27:16,009 --> 00:27:12,570
it does but the rate constant for for

599
00:27:19,399 --> 00:27:16,019
amid formation relative to hydrolysis is

600
00:27:21,700 --> 00:27:19,409
in the order of a hundred thousand at an

601
00:27:24,019 --> 00:27:21,710
accessible pH which is about eight I

602
00:27:26,120 --> 00:27:24,029
don't know another reaction like it and

603
00:27:31,879 --> 00:27:26,130
that's one of the arguments for the do

604
00:27:35,600 --> 00:27:31,889
sort of approach to things so what are

605
00:27:39,529 --> 00:27:35,610
we doing our interest is in trying to

606
00:27:43,039 --> 00:27:39,539
design networks that enable us to learn

607
00:27:46,450 --> 00:27:43,049
something about complexity on a scale

608
00:27:49,399 --> 00:27:46,460
that is similar to that of metabolism

609
00:27:52,509 --> 00:27:49,409
similar meaning we like something that

610
00:27:55,340 --> 00:27:52,519
looks the same order of magnitude

611
00:27:56,840 --> 00:27:55,350
complexity as the Krebs cycle what we're

612
00:27:58,879 --> 00:27:56,850
working on is simpler than the Krebs

613
00:28:01,100 --> 00:27:58,889

cycle and I'll show you in a minute but

614
00:28:05,000 --> 00:28:01,110
we like something is roughly that order

615
00:28:05,840 --> 00:28:05,010
of magnitude so our choices we're going

616
00:28:07,549 --> 00:28:05,850
to make Ammons

617
00:28:11,570 --> 00:28:07,559
because they're important for proteins

618
00:28:13,970 --> 00:28:11,580
and peptides via thio esters what we're

619
00:28:17,769 --> 00:28:13,980
missing and I know this to be true is

620
00:28:21,200 --> 00:28:17,779
we're missing catalysts that provide

621
00:28:23,330 --> 00:28:21,210
control and that is the key to meta

622
00:28:25,430 --> 00:28:23,340
metabolism it's not the reactions per se

623
00:28:28,759 --> 00:28:25,440
it's the catalysts which turn one

624
00:28:30,649 --> 00:28:28,769
another on and off we need simple

625
00:28:32,440 --> 00:28:30,659
organic chemistry so nothing complicated

626
00:28:35,899 --> 00:28:32,450
no Swiss postdocs

627
00:28:38,149 --> 00:28:35,909
we are going to be using as our product

628
00:28:40,430 --> 00:28:38,159
not the chemical reaction but rather

629
00:28:42,919 --> 00:28:40,440
oscillations because that's a complex

630
00:28:44,930 --> 00:28:42,929
behavior and it's pretty easy to follow

631
00:28:48,019 --> 00:28:44,940
so you need as we were discussing

632
00:28:50,060 --> 00:28:48,029
earlier we need an observable we're

633
00:28:53,240 --> 00:28:50,070
going to include a mass transport step

634
00:28:56,419 --> 00:28:53,250
and I can discuss this with you as well

635
00:28:58,310 --> 00:28:56,429
but our major shortfall is that we don't

636
00:29:00,980 --> 00:28:58,320
have good approaches to catalysis and

637
00:29:02,269 --> 00:29:00,990
catalysis in my view is one of the key

638
00:29:04,570 --> 00:29:02,279

things that we're missing in this whole

639
00:29:10,190 --> 00:29:06,800
so krebs cycle

640
00:29:12,050 --> 00:29:10,200
the only point to make here is that it

641
00:29:14,210 --> 00:29:12,060
does the same kind of thing that we're

642
00:29:16,970 --> 00:29:14,220
interested in it's a simple input which

643
00:29:19,490 --> 00:29:16,980
is a thio ester and what we don't have

644
00:29:22,550 --> 00:29:19,500
is that every one of these steps has a

645
00:29:24,110 --> 00:29:22,560
catalyst some of the catalysts look very

646
00:29:26,480 --> 00:29:24,120
much like things that could come out of

647
00:29:29,540 --> 00:29:26,490
prebiotic chemistry all of these things

648
00:29:31,490 --> 00:29:29,550
look that way but we don't actually have

649
00:29:34,940 --> 00:29:31,500
ways of connecting the prebiotic

650
00:29:37,660 --> 00:29:34,950
chemistry to these sorts of reactions so

651
00:29:40,670 --> 00:29:37,670
in principle it looks good in practice

652
00:29:42,980 --> 00:29:40,680
the activities of the little iron sulfur

653
00:29:45,470 --> 00:29:42,990
clusters and iron manganese sulfur

654
00:29:47,330 --> 00:29:45,480
clusters have to be modulated in ways

655
00:29:49,610 --> 00:29:47,340
that we don't understand how to do right

656
00:29:51,950 --> 00:29:49,620
now and things like a nimitta soil

657
00:29:53,510 --> 00:29:51,960
phosphate simple piece but we actually

658
00:29:58,190 --> 00:29:53,520
don't know how to make images or

659
00:29:59,870 --> 00:29:58,200
phosphates so let me tell you about the

660
00:30:03,500 --> 00:29:59,880
experiment and I want you to think of

661
00:30:05,720 --> 00:30:03,510
this in terms of an analogy and the one

662
00:30:09,350 --> 00:30:05,730
that I keep coming back to is is life a

663
00:30:10,250 --> 00:30:09,360

flame but what's a flame you put in an

664
00:30:12,860 --> 00:30:10,260
oxidant

665
00:30:16,130 --> 00:30:12,870
I'm sorry reductant you mix it with an

666
00:30:18,290 --> 00:30:16,140
oxidant so methane and oxygen there's an

667
00:30:21,260 --> 00:30:18,300
organized structure the organized

668
00:30:23,990 --> 00:30:21,270
structure is probably with methane

669
00:30:25,820 --> 00:30:24,000
oxygen it's in the order of 10,000

670
00:30:28,210 --> 00:30:25,830
reactions something like that we don't

671
00:30:30,440 --> 00:30:28,220
really understand it and anything more

672
00:30:32,150 --> 00:30:30,450
elaborate than methane we don't

673
00:30:36,620 --> 00:30:32,160
understand at all there are no models

674
00:30:38,450 --> 00:30:36,630
for those systems but these two oxygen

675
00:30:40,520 --> 00:30:38,460
and methane produce an organized

676
00:30:43,100 --> 00:30:40,530
structure which does something it gives

677
00:30:46,970 --> 00:30:43,110
off heat and light and converts methane

678
00:30:49,250 --> 00:30:46,980
into carbon dioxide and water and if you

679
00:30:51,320 --> 00:30:49,260
want to you can put in various sorts of

680
00:30:52,880 --> 00:30:51,330
machinery here to make it to do pretty

681
00:30:58,310 --> 00:30:52,890
interesting things I won't go through

682
00:31:00,800 --> 00:30:58,320
this here we say a cell is a structure

683
00:31:03,140 --> 00:31:00,810
looks like this into which goes

684
00:31:06,230 --> 00:31:03,150
nutrients glucose oxygen some other

685
00:31:08,210 --> 00:31:06,240
stuff and what comes out of it is waste

686
00:31:10,450 --> 00:31:08,220
and what it does instead of generating

687
00:31:14,180 --> 00:31:10,460
heat and light is to make another cell

688
00:31:17,039 --> 00:31:14,190

you say quite correctly that is an

689
00:31:20,310 --> 00:31:17,049
analogy so loose and so sloppy that

690
00:31:23,840 --> 00:31:20,320
only decrepit to geriatric old man would

691
00:31:25,889 --> 00:31:23,850
come up with that kind of thing got it

692
00:31:29,190 --> 00:31:25,899
geriatric decrepit old man I've

693
00:31:30,989 --> 00:31:29,200
qualified they or at least we're going

694
00:31:33,090 --> 00:31:30,999
to add one component to it which is

695
00:31:36,419 --> 00:31:33,100
what's called by chemical engineers a

696
00:31:38,700 --> 00:31:36,429
continuous stirred-tank reactor and this

697
00:31:41,519 --> 00:31:38,710
is just basically something in which's

698
00:31:43,529 --> 00:31:41,529
reactor little container reactants can

699
00:31:45,690 --> 00:31:43,539
go in products can go out and there's a

700
00:31:47,310 --> 00:31:45,700
stirrer you say what does that have to

701
00:31:50,639 --> 00:31:47,320
do into anything and that is it's

702
00:31:52,560 --> 00:31:50,649
exactly like this reactants go in here

703
00:31:54,419 --> 00:31:52,570
there's no mechanical stirring well

704
00:31:56,940 --> 00:31:54,429
there actually is some but it's that's

705
00:31:59,489 --> 00:31:56,950
not the key issue this is smaller so

706
00:32:00,899 --> 00:31:59,499
diffusion allows everything to mix here

707
00:32:02,609 --> 00:32:00,909
because it's a little bit bigger it's

708
00:32:04,080 --> 00:32:02,619
more convenient to have a stirrer but

709
00:32:06,570 --> 00:32:04,090
it's not absolutely necessary

710
00:32:09,210 --> 00:32:06,580
so I'm saying a cell is like a

711
00:32:14,340 --> 00:32:09,220
continuous stirred reactor and like a

712
00:32:16,200 --> 00:32:14,350
flame and here's the actual system not

713
00:32:19,710 --> 00:32:16,210

important the details here you have a

714
00:32:21,779 --> 00:32:19,720
mixer we feed reactants into it we have

715
00:32:24,180 --> 00:32:21,789
a thermostat it not important the

716
00:32:29,009 --> 00:32:24,190
products come out of it we analyze them

717
00:32:34,169 --> 00:32:29,019
and that's all that happens now what's

718
00:32:37,649 --> 00:32:34,179
the chemistry I put this up because it's

719
00:32:39,450 --> 00:32:37,659
like taking a typical organic chemistry

720
00:32:41,879 --> 00:32:39,460
class and putting up differential

721
00:32:44,430 --> 00:32:41,889
equations every look so everyone looks

722
00:32:45,960 --> 00:32:44,440
at it for about seven microseconds their

723
00:32:48,810 --> 00:32:45,970
mind goes blank and they start thinking

724
00:32:50,489 --> 00:32:48,820
about something else dinner and so I'm

725
00:32:52,830 --> 00:32:50,499
not going to spend time on it the only

726
00:32:56,039 --> 00:32:52,840
issue is that what happens here is that

727
00:32:58,739 --> 00:32:56,049
you take a thio ester this one you

728
00:33:03,090 --> 00:32:58,749
convert it into a product which is an

729
00:33:06,299 --> 00:33:03,100
amide let me find it here you're damaged

730
00:33:08,099 --> 00:33:06,309
and every time you do that you make two

731
00:33:09,539 --> 00:33:08,109
molecules of the thought you make two

732
00:33:11,999 --> 00:33:09,549
molecules of the reactants that are

733
00:33:16,289 --> 00:33:12,009
involved so it is a design to auto

734
00:33:17,700 --> 00:33:16,299
amplifying reaction and the details I'm

735
00:33:21,060 --> 00:33:17,710
happy to go through it with anybody

736
00:33:22,409 --> 00:33:21,070
who's interested but there's a point

737
00:33:25,440 --> 00:33:22,419
which is actually a quite interesting

738
00:33:29,249 --> 00:33:25,450

point here you can describe all of this

739
00:33:30,460 --> 00:33:29,259
with a set of about I think it's six or

740
00:33:33,850 --> 00:33:30,470
seven couple

741
00:33:35,890 --> 00:33:33,860
rental equations I should say as an

742
00:33:39,039 --> 00:33:35,900
organic chemist that organic chemists do

743
00:33:41,649 --> 00:33:39,049
not do coupled differential or we just

744
00:33:45,130 --> 00:33:41,659
don't do that and the trouble is that

745
00:33:46,930 --> 00:33:45,140
even if you do do it you can look at

746
00:33:48,789 --> 00:33:46,940
such a set of reactions and work them

747
00:33:52,899 --> 00:33:48,799
through but it doesn't actually tell you

748
00:33:54,850 --> 00:33:52,909
very much so we spent some time worrying

749
00:33:57,880 --> 00:33:54,860
about what language we use to describe

750
00:33:59,860 --> 00:33:57,890
that and what we've settled on is this

751
00:34:01,960 --> 00:33:59,870
and I recommend it to you to think about

752
00:34:04,360 --> 00:34:01,970
when you're thinking about the cell we

753
00:34:06,850 --> 00:34:04,370
use what's very common in in electronics

754
00:34:08,530 --> 00:34:06,860
and also in chemical engineering wishes

755
00:34:12,820 --> 00:34:08,540
to use something called control theory

756
00:34:14,589 --> 00:34:12,830
and in control theory you ultimately get

757
00:34:16,419 --> 00:34:14,599
around a differential equations but you

758
00:34:20,080 --> 00:34:16,429
think about things rather in terms of

759
00:34:21,310 --> 00:34:20,090
functional blocks so all that's involved

760
00:34:24,010 --> 00:34:21,320
in what I told you is that we have

761
00:34:25,990 --> 00:34:24,020
reactants and they're flowing at some

762
00:34:29,290 --> 00:34:26,000
rate into the reactor this is the

763
00:34:31,119 --> 00:34:29,300

continuous stirred-tank reactor some of

764
00:34:33,669 --> 00:34:31,129
these reactants cause a trigger

765
00:34:36,070 --> 00:34:33,679
well I've acutely let me do this the

766
00:34:39,250 --> 00:34:36,080
auto amplification reaction is the key

767
00:34:41,320 --> 00:34:39,260
step in an auto amplifying reaction you

768
00:34:43,270 --> 00:34:41,330
trigger it and the rate goes up

769
00:34:46,599 --> 00:34:43,280
exponentially that's the characteristic

770
00:34:49,869 --> 00:34:46,609
of auto amplification so what we have to

771
00:34:52,240 --> 00:34:49,879
have is a trigger for this and we can

772
00:34:54,310 --> 00:34:52,250
design the trigger the trigger sets off

773
00:34:56,589 --> 00:34:54,320
the auto amplification the auto

774
00:34:59,589 --> 00:34:56,599
amplification eats all of the reactants

775
00:35:02,020 --> 00:34:59,599
and then we wash it out and reload it by

776
00:35:03,910 --> 00:35:02,030
this continuous stream so that what you

777
00:35:07,450 --> 00:35:03,920
have to do all you have to do in a sense

778
00:35:10,240 --> 00:35:07,460
is organize the rate at which reactants

779
00:35:13,240 --> 00:35:10,250
go in the concentration of the reactants

780
00:35:14,680 --> 00:35:13,250
and you will see there is behaviors and

781
00:35:18,190 --> 00:35:14,690
the one that we see is an oscillation

782
00:35:20,079 --> 00:35:18,200
that looks like that and the reactants

783
00:35:24,000 --> 00:35:20,089
are all reactants that are plausibly

784
00:35:26,170 --> 00:35:24,010
present in prebiotic chemistry this

785
00:35:28,990 --> 00:35:26,180
arguably knocked but the rest of those

786
00:35:31,630 --> 00:35:29,000
could certainly have been there so

787
00:35:34,210 --> 00:35:31,640
limiting cases one is that if we flow

788
00:35:36,430 --> 00:35:34,220

stuff too fast or too slow you just have

789
00:35:39,250 --> 00:35:36,440
steady state but if you do it the right

790
00:35:42,040 --> 00:35:39,260
way you have oscillations and so we

791
00:35:44,440 --> 00:35:42,050
observe the oscillations this is an in

792
00:35:48,370 --> 00:35:44,450
the order of the degree of complexity of

793
00:35:50,200 --> 00:35:48,380
the krebs cycle and it shows some really

794
00:35:52,630 --> 00:35:50,210
interesting behavior this is all now

795
00:35:58,299 --> 00:35:52,640
occurring spontaneously one of them is

796
00:36:00,339 --> 00:35:58,309
that if you go forward that is you

797
00:36:03,519 --> 00:36:00,349
increase the flow rate in one way you

798
00:36:04,900 --> 00:36:03,529
see multiple steady states in the

799
00:36:06,880 --> 00:36:04,910
product that we're looking at here's a

800
00:36:09,250 --> 00:36:06,890
steady state there's another there's

801
00:36:12,130 --> 00:36:09,260
another there's another but if you go

802
00:36:13,900 --> 00:36:12,140
backwards this is what you see here if

803
00:36:15,880 --> 00:36:13,910
you go backwards you see totally

804
00:36:19,750 --> 00:36:15,890
different behavior that is you increase

805
00:36:21,009 --> 00:36:19,760
the the rate constant for flowing the

806
00:36:24,160 --> 00:36:21,019
liquid into the reactor

807
00:36:26,769 --> 00:36:24,170
you see stationary States but if you

808
00:36:29,470 --> 00:36:26,779
decrease the rate going backwards you

809
00:36:30,789 --> 00:36:29,480
see no such stationary stage you see

810
00:36:33,549 --> 00:36:30,799
something that's totally different

811
00:36:36,789 --> 00:36:33,559
this kind of complexity is the kind of

812
00:36:39,339 --> 00:36:36,799
thing that one can imagine using for

813
00:36:42,370 --> 00:36:39,349

making something more complicated here

814
00:36:44,349 --> 00:36:42,380
is oscillations and the one problem with

815
00:36:47,440 --> 00:36:44,359
this system I should say experimentally

816
00:36:50,470 --> 00:36:47,450
is that the oscillations are slow there

817
00:36:53,410 --> 00:36:50,480
it's one every hour or so so we have to

818
00:36:55,539 --> 00:36:53,420
make them faster but if you look at the

819
00:36:59,019 --> 00:36:55,549
space velocity which is the number of

820
00:37:01,269 --> 00:36:59,029
times per second that the contents of

821
00:37:04,120 --> 00:37:01,279
the reactor are exchanged and you know

822
00:37:06,400 --> 00:37:04,130
these are 10 to minus 4 or so when you

823
00:37:07,990 --> 00:37:06,410
get down here you have a kind of

824
00:37:10,359 --> 00:37:08,000
stationary stage in which you turn the

825
00:37:13,089 --> 00:37:10,369
system on and we'll do that that is the

826
00:37:16,029 --> 00:37:13,099
oscillations will go away in here

827
00:37:18,370 --> 00:37:16,039
you have nice oscillations and you go

828
00:37:21,700 --> 00:37:18,380
over here and the oscillations go away

829
00:37:23,200 --> 00:37:21,710
and it's not over a very wide range of

830
00:37:25,960 --> 00:37:23,210
space velocities this is a pretty

831
00:37:29,370 --> 00:37:25,970
delicate system and I'll show you why

832
00:37:37,269 --> 00:37:34,210
now you say let me go back to this you

833
00:37:40,839 --> 00:37:37,279
say I say that this kind of complex

834
00:37:43,089 --> 00:37:40,849
behavior only occurs in a narrow region

835
00:37:45,339 --> 00:37:43,099
that doesn't sound like the kind of

836
00:37:48,789 --> 00:37:45,349
thing that one wants to have when one is

837
00:37:50,920 --> 00:37:48,799
thinking about a kind of chemistry that

838
00:37:57,700 --> 00:37:50,930

might model something that was involved

839
00:38:06,190 --> 00:38:01,180
action of metabolism so it looks too

840
00:38:08,680 --> 00:38:06,200
fragile and anyway the environment then

841
00:38:10,690 --> 00:38:08,690
did not have clean reactions it had

842
00:38:13,420 --> 00:38:10,700
variable temperature at the variable

843
00:38:14,260 --> 00:38:13,430
flow rates you know maybe all of this is

844
00:38:16,210 --> 00:38:14,270
just nonsense

845
00:38:20,050 --> 00:38:16,220
and so we've sent out to look at this

846
00:38:22,000 --> 00:38:20,060
subject of robustness and so this fits

847
00:38:23,440 --> 00:38:22,010
in with something which is I think a

848
00:38:26,950 --> 00:38:23,450
very interesting question which is

849
00:38:29,500 --> 00:38:26,960
Darwinian evolution now an argument with

850
00:38:32,589 --> 00:38:29,510
Darwin and evolution which will come to

851
00:38:35,410 --> 00:38:32,599
an amended as finches and finches which

852
00:38:38,109 --> 00:38:35,420
adapt themselves through evolution to be

853
00:38:40,240 --> 00:38:38,119
specialized for picking pinecones out of

854
00:38:42,790 --> 00:38:40,250
bark and things of that kind

855
00:38:45,670 --> 00:38:42,800
so specialization which led to the

856
00:38:47,380 --> 00:38:45,680
fastest cheetah or the fastest year or

857
00:38:50,410 --> 00:38:47,390
the best beak you know optimise

858
00:38:52,329 --> 00:38:50,420
performance but it's not absolutely

859
00:38:54,640 --> 00:38:52,339
obvious that that's the right vector at

860
00:38:56,560 --> 00:38:54,650
the beginning because you don't have to

861
00:38:58,660 --> 00:38:56,570
worry about competition with species if

862
00:39:00,700 --> 00:38:58,670
there were no species to compete it's

863
00:39:02,320 --> 00:39:00,710

just not an issue so maybe it's a

864
00:39:03,910 --> 00:39:02,330
different story and what you want is

865
00:39:06,670 --> 00:39:03,920
something that's the most durable and

866
00:39:09,250 --> 00:39:06,680
robust system not the most specialized

867
00:39:11,290 --> 00:39:09,260
system and we wanted to see if we can

868
00:39:13,329 --> 00:39:11,300
find any evidence for that one way or

869
00:39:14,859 --> 00:39:13,339
the other so what we're going to do is

870
00:39:16,390 --> 00:39:14,869
to do the following thing we're going to

871
00:39:20,230 --> 00:39:16,400
take the system that I just showed you

872
00:39:22,500 --> 00:39:20,240
and we're going to vary things so here

873
00:39:24,670 --> 00:39:22,510
the finches that I just talked about and

874
00:39:28,000 --> 00:39:24,680
what we've done is simply to take

875
00:39:30,460 --> 00:39:28,010
instead of one reset of reactions I'm

876
00:39:33,460 --> 00:39:30,470
going to take two set of reactions I'm

877
00:39:35,980 --> 00:39:33,470
going to add 2 cos ters and see what

878
00:39:38,320 --> 00:39:35,990
happens so I've got a mixture you know a

879
00:39:39,670 --> 00:39:38,330
minimal mixture and in doing this we've

880
00:39:43,270 --> 00:39:39,680
seen something which is quite

881
00:39:44,950 --> 00:39:43,280
interesting quite intriguing and let's

882
00:39:47,260 --> 00:39:44,960
not worry about the details here other

883
00:39:49,839 --> 00:39:47,270
than to say that we have different

884
00:39:53,440 --> 00:39:49,849
structures than amino acids and what

885
00:39:56,230 --> 00:39:53,450
these truth tables here show is that if

886
00:40:00,190 --> 00:39:56,240
we take a system that contains alanine

887
00:40:02,620 --> 00:40:00,200
bio ester glycine thio ester with

888
00:40:04,900 --> 00:40:02,630

glycine and glycine imagine we're doing

889
00:40:06,760 --> 00:40:04,910
this with two come to systems and we

890
00:40:10,000 --> 00:40:06,770
just mix glycine glycine so it's just

891
00:40:12,219 --> 00:40:10,010
glycine it doesn't oscillate alanine

892
00:40:14,469 --> 00:40:12,229
with alanine always

893
00:40:17,939 --> 00:40:14,479
but what's important is it if you mix

894
00:40:21,640 --> 00:40:17,949
alanine with glycine it still oscillates

895
00:40:23,799 --> 00:40:21,650
so what we see is that if you have a

896
00:40:26,890 --> 00:40:23,809
system it's oscillating it can in train

897
00:40:29,410 --> 00:40:26,900
an on oscillating system so it's

898
00:40:34,209 --> 00:40:29,420
actually more robust as a mixture than

899
00:40:36,279 --> 00:40:34,219
otherwise and even more remarkably if we

900
00:40:39,489 --> 00:40:36,289
take a system of glycine which doesn't

901
00:40:41,650 --> 00:40:39,499
oscillate glycine glycine and a system

902
00:40:43,630 --> 00:40:41,660
of this amino acid which doesn't

903
00:40:45,489 --> 00:40:43,640
oscillate neither one of them oscillate

904
00:40:48,699 --> 00:40:45,499
and we put them together and they do

905
00:40:51,489 --> 00:40:48,709
oscillate so it's a very primitive

906
00:40:54,370 --> 00:40:51,499
result but what it says is that in this

907
00:40:56,079 --> 00:40:54,380
kind of evolutionary issue it actually

908
00:41:00,009 --> 00:40:56,089
might be the case that mixtures are

909
00:41:01,650 --> 00:41:00,019
preferred and in fact you can make an

910
00:41:03,969 --> 00:41:01,660
argument in a number of circumstances

911
00:41:06,099 --> 00:41:03,979
the darwin may have had the right answer

912
00:41:08,650 --> 00:41:06,109
but not quite the right question and

913
00:41:10,779 --> 00:41:08,660

that is when you have species that are

914
00:41:13,959 --> 00:41:10,789
that are optimized maybe you want

915
00:41:16,269 --> 00:41:13,969
specialization but for robustness what

916
00:41:17,979 --> 00:41:16,279
you might want is a mixture of species

917
00:41:19,539 --> 00:41:17,989
some of which do really well in some

918
00:41:21,249 --> 00:41:19,549
circumstances and some of which do

919
00:41:23,819 --> 00:41:21,259
really well in other circumstances and

920
00:41:26,199 --> 00:41:23,829
which cover the range but don't

921
00:41:28,749 --> 00:41:26,209
individually are not individually the

922
00:41:30,969 --> 00:41:28,759
best for some particular circumstance

923
00:41:32,829 --> 00:41:30,979
and I think that's important because it

924
00:41:34,059 --> 00:41:32,839
gets around in principle some of these

925
00:41:40,689 --> 00:41:34,069
problems of how do you deal with

926
00:41:42,819 --> 00:41:40,699
mixtures so what I just said but now I

927
00:41:44,289 --> 00:41:42,829
want to answer raise a question which I

928
00:41:46,539 --> 00:41:44,299
can't answer which is the one that's

929
00:41:48,130 --> 00:41:46,549
here this is all very interesting

930
00:41:50,529 --> 00:41:48,140
chemistry and it does tell us something

931
00:41:53,439 --> 00:41:50,539
about dissipative systems but is it

932
00:41:55,959 --> 00:41:53,449
relevant to this and my good friend Jack

933
00:41:58,509 --> 00:41:55,969
szostak would say this is total nonsense

934
00:42:00,189 --> 00:41:58,519
it has nothing to do with anything and I

935
00:42:02,259 --> 00:42:00,199
would say to my good friend Jack szostak

936
00:42:04,719 --> 00:42:02,269
RNA is a wonderful molecule but you're

937
00:42:07,269 --> 00:42:04,729
never going to get it so we tend to look

938
00:42:09,239 --> 00:42:07,279

at one another across the table and go

939
00:42:17,709 --> 00:42:09,249
have lunch

940
00:42:18,789 --> 00:42:17,719
alright so sure I quit at this point all

941
00:42:20,079 --> 00:42:18,799
right well let me quickly go through

942
00:42:24,860 --> 00:42:20,089
this because there's an important

943
00:42:31,010 --> 00:42:27,650
and that is that how do we know when

944
00:42:32,690 --> 00:42:31,020
we've succeeded how do we know what's

945
00:42:36,590 --> 00:42:32,700
what's the first sign of life and I

946
00:42:39,110 --> 00:42:36,600
don't have any idea but there's an

947
00:42:42,050 --> 00:42:39,120
interesting question that I can ask here

948
00:42:44,540 --> 00:42:42,060
what is life when I I'm a chemist and

949
00:42:46,520 --> 00:42:44,550
you know chemists - chemists the world

950
00:42:48,830 --> 00:42:46,530
starts with electrons and nuclei and you

951
00:42:51,520 --> 00:42:48,840
build everything that way when I go to

952
00:42:54,050 --> 00:42:51,530
my friends who are physicists and I say

953
00:42:56,750 --> 00:42:54,060
humble chemist and the humble chemist

954
00:42:58,460 --> 00:42:56,760
what's an electron and I get the same

955
00:43:02,900 --> 00:42:58,470
answer every time and that is they look

956
00:43:06,320 --> 00:43:02,910
at me with a certain condescension and

957
00:43:08,660 --> 00:43:06,330
say you can't ask that question you

958
00:43:12,050 --> 00:43:08,670
cannot ask it is not a legitimate

959
00:43:14,620 --> 00:43:12,060
question to ask what an electron is you

960
00:43:17,870 --> 00:43:14,630
can only ask what an electron does

961
00:43:20,150 --> 00:43:17,880
different question and so we may not be

962
00:43:24,620 --> 00:43:20,160
able to ask the question of what life is

963
00:43:25,880 --> 00:43:24,630

but we can ask what life does and it's a

964
00:43:30,350 --> 00:43:25,890
different way of thinking about the

965
00:43:33,740 --> 00:43:30,360
problem so these are all things that we

966
00:43:37,280 --> 00:43:33,750
know bounded and compartmentalize so we

967
00:43:39,560 --> 00:43:37,290
can do that cyclic yes adaptive yes

968
00:43:42,050 --> 00:43:39,570
memory we don't quite know how that's

969
00:43:44,870 --> 00:43:42,060
fitting in the beginning in water let's

970
00:43:46,750 --> 00:43:44,880
assume it and then the three things that

971
00:43:49,460 --> 00:43:46,760
I think are most interesting are in red

972
00:43:51,650 --> 00:43:49,470
it's out of equilibrium in dissipative

973
00:43:56,900 --> 00:43:51,660
and what does that have to do with what

974
00:43:59,840 --> 00:43:56,910
goes on here it's alive yes and is it

975
00:44:02,090 --> 00:43:59,850
emergent and what I mean by that without

976
00:44:05,360 --> 00:44:02,100
getting into the semantic swamps of what

977
00:44:08,780 --> 00:44:05,370
emergence means is there some principle

978
00:44:10,610 --> 00:44:08,790
in statistics in probability in thinking

979
00:44:13,430 --> 00:44:10,620
about robustness and all the rest of

980
00:44:15,380 --> 00:44:13,440
these things that we don't get are we

981
00:44:17,120 --> 00:44:15,390
assuming that we know completely

982
00:44:20,480 --> 00:44:17,130
everything that needs to be known to

983
00:44:22,550 --> 00:44:20,490
answer this problem and we know what we

984
00:44:23,930 --> 00:44:22,560
know so the answer is always to this

985
00:44:25,640 --> 00:44:23,940
question always going to be yes

986
00:44:28,880 --> 00:44:25,650
unless you're cautious in which point

987
00:44:34,130 --> 00:44:28,890
you say quantum mechanics in 1900 didn't

988
00:44:37,040 --> 00:44:34,140

exist and that's important so let's not

989
00:44:38,130 --> 00:44:37,050
spend time on that other than one

990
00:44:40,620 --> 00:44:38,140
question

991
00:44:44,930 --> 00:44:40,630
what are the limits to reductionism good

992
00:44:49,529 --> 00:44:44,940
question but think about this just a bit

993
00:44:52,470 --> 00:44:49,539
or alive not alive and dead partially

994
00:44:55,890 --> 00:44:52,480
dead other than alive how do we think

995
00:44:59,130 --> 00:44:55,900
about those words it's very interesting

996
00:45:04,019 --> 00:44:59,140
we don't actually have a word for a

997
00:45:06,240 --> 00:45:04,029
stone we have a word for a live and then

998
00:45:08,670 --> 00:45:06,250
we define everything by being not what

999
00:45:10,890 --> 00:45:08,680
you are but there might be lots of

1000
00:45:12,240 --> 00:45:10,900
states that are not what you are but we

1001
00:45:15,059 --> 00:45:12,250
don't have any words for any of them and

1002
00:45:18,779 --> 00:45:15,069
what you don't name what you can't name

1003
00:45:21,150 --> 00:45:18,789
you can't think about so let me just ask

1004
00:45:24,059 --> 00:45:21,160
which of these are alive there's a

1005
00:45:29,370 --> 00:45:24,069
frozen embryo alive there are no

1006
00:45:32,400 --> 00:45:29,380
reactions megacity megacity to me has

1007
00:45:34,890 --> 00:45:32,410
all the characteristics of a cell but

1008
00:45:37,680 --> 00:45:34,900
the organism doesn't have molecules it

1009
00:45:41,309 --> 00:45:37,690
has people the world wide web without

1010
00:45:42,890 --> 00:45:41,319
people world wide web with people and

1011
00:45:45,960 --> 00:45:42,900
one of these should be with and without

1012
00:45:49,140 --> 00:45:45,970
the Internet of Things in 2080 I chose

1013
00:45:51,509 --> 00:45:49,150

that 50 years from now so is that going

1014
00:45:54,749 --> 00:45:51,519
to be alive we don't know the answer

1015
00:45:56,249 --> 00:45:54,759
there the Internet of Things a virus

1016
00:45:57,870 --> 00:45:56,259
inside a cell all the rest of those

1017
00:46:01,349 --> 00:45:57,880
things could there be life that's

1018
00:46:02,910 --> 00:46:01,359
completely different from ours and I

1019
00:46:04,950 --> 00:46:02,920
think we should think about that in

1020
00:46:06,690 --> 00:46:04,960
terms of something looks like this and

1021
00:46:10,200 --> 00:46:06,700
there's just one or two more diagrams I

1022
00:46:12,420 --> 00:46:10,210
wanted to show to finish off suppose we

1023
00:46:14,490 --> 00:46:12,430
think about some kind of metric here

1024
00:46:16,440 --> 00:46:14,500
complexity or complicatedness or

1025
00:46:20,970 --> 00:46:16,450
something else proximity to life and

1026
00:46:26,099 --> 00:46:20,980
then aliveness is there a continuum

1027
00:46:29,730 --> 00:46:26,109
there does you go smoothly from this to

1028
00:46:32,430 --> 00:46:29,740
fully alive or is it something looks

1029
00:46:35,160 --> 00:46:32,440
like this and if you look at any variant

1030
00:46:37,109 --> 00:46:35,170
in complexity what you find is that

1031
00:46:39,299 --> 00:46:37,119
there are all kinds of responses between

1032
00:46:41,640 --> 00:46:39,309
an input function and output function

1033
00:46:45,630 --> 00:46:41,650
and I have no idea what dimensionality

1034
00:46:48,870 --> 00:46:45,640
of space binary it's just not alive and

1035
00:46:50,579 --> 00:46:48,880
then it's alive here you might say well

1036
00:46:52,049 --> 00:46:50,589
it's not alive and it gets more alive

1037
00:46:54,599 --> 00:46:52,059
rapidly as it goes on

1038
00:46:56,549 --> 00:46:54,609

but it's really these kinds of functions

1039
00:46:59,759 --> 00:46:56,559
that I think are most interesting these

1040
00:47:02,249 --> 00:46:59,769
bifurcations and multiple dimensions and

1041
00:47:04,559 --> 00:47:02,259
in this kind of thing you you have

1042
00:47:07,099 --> 00:47:04,569
something become more complicated and at

1043
00:47:09,689 --> 00:47:07,109
some point something happens and

1044
00:47:12,029 --> 00:47:09,699
something happens involves a transition

1045
00:47:14,579 --> 00:47:12,039
but then you change it and you move it

1046
00:47:16,799 --> 00:47:14,589
down and something else happens those of

1047
00:47:19,769 --> 00:47:16,809
you who know about complexity know about

1048
00:47:22,229 --> 00:47:19,779
this kind of thing but I note that as a

1049
00:47:26,549 --> 00:47:22,239
as I go through I have gone through a

1050
00:47:28,859 --> 00:47:26,559
process of being fertilized ovum I got

1051
00:47:31,319 --> 00:47:28,869
more complicated I became a little piece

1052
00:47:33,539 --> 00:47:31,329
of meat which is called a baby and then

1053
00:47:35,670 --> 00:47:33,549
more complicated more complicated at

1054
00:47:38,519 --> 00:47:35,680
some point I'm going to die and when I

1055
00:47:41,189 --> 00:47:38,529
die when I'm dead by everybody's

1056
00:47:44,509 --> 00:47:41,199
definition my toenails and my hair will

1057
00:47:47,219 --> 00:47:44,519
continue to grow for a long while now

1058
00:47:51,239 --> 00:47:47,229
what part of me at what point do we

1059
00:47:53,069 --> 00:47:51,249
define me as not alive and you know what

1060
00:47:54,900 --> 00:47:53,079
happens is the brain goes off the brain

1061
00:47:57,049 --> 00:47:54,910
goes off the heart goes off you stop

1062
00:47:59,579 --> 00:47:57,059
delivering tissue metabolism starts

1063
00:48:03,390 --> 00:47:59,589

where did I just say metabolism stops

1064
00:48:05,819 --> 00:48:03,400
and that I think is probably a greater

1065
00:48:08,419 --> 00:48:05,829
criterion for alive or not alive but I'm

1066
00:48:12,359 --> 00:48:08,429
not sure exactly how to think about it

1067
00:48:16,380 --> 00:48:12,369
so just two final slides what are we

1068
00:48:17,339 --> 00:48:16,390
missing this community in my view

1069
00:48:19,890 --> 00:48:17,349
doesn't know very much about

1070
00:48:22,549 --> 00:48:19,900
thermodynamics statistics probability or

1071
00:48:25,620 --> 00:48:22,559
information and I think it's important

1072
00:48:27,689 --> 00:48:25,630
catalysis I would love to make progress

1073
00:48:30,870 --> 00:48:27,699
in catalysis but I haven't had any good

1074
00:48:32,849 --> 00:48:30,880
ideas yet dissipative systems the

1075
00:48:36,929 --> 00:48:32,859
Leventhal paradox how many of you know

1076
00:48:38,849 --> 00:48:36,939
what the Leventhal paradox is it's a

1077
00:48:40,259 --> 00:48:38,859
it's a good illustrative example maybe

1078
00:48:41,880 --> 00:48:40,269
we'll talk about it at the end that

1079
00:48:43,319 --> 00:48:41,890
somebody asks a relevant question so

1080
00:48:45,049 --> 00:48:43,329
somebody raised their hand and talked

1081
00:48:47,459 --> 00:48:45,059
about the level caller question

1082
00:48:49,289 --> 00:48:47,469
combinatorial chemistry has been a

1083
00:48:51,059 --> 00:48:49,299
complete failure because we don't know

1084
00:48:53,339 --> 00:48:51,069
how much how many things we need to have

1085
00:48:55,859 --> 00:48:53,349
all the rest of these kinds of things

1086
00:48:57,569 --> 00:48:55,869
what I'm saying is we're missing we have

1087
00:48:59,729 --> 00:48:57,579
organic chemists doing good organic

1088
00:49:02,789 --> 00:48:59,739

chemistry we have by always just doing

1089
00:49:05,099 --> 00:49:02,799
good biological chemistry but we've

1090
00:49:05,830 --> 00:49:05,109
completely left out so far the physical

1091
00:49:08,170 --> 00:49:05,840
chemistry and

1092
00:49:11,380 --> 00:49:08,180
physics to provide concepts along the

1093
00:49:14,590 --> 00:49:11,390
way and then here's stuff that you can

1094
00:49:17,100 --> 00:49:14,600
just read as you think about it not

1095
00:49:19,990 --> 00:49:17,110
important enough to go through here and

1096
00:49:21,640 --> 00:49:20,000
that's really what I have to say but

1097
00:49:24,190 --> 00:49:21,650
what I would conclude with is just a

1098
00:49:26,910 --> 00:49:24,200
short statement that if you look at what

1099
00:49:29,860 --> 00:49:26,920
we know so far we have wonderful pieces

1100
00:49:31,630 --> 00:49:29,870
progress in a number of areas but we

1101
00:49:33,970 --> 00:49:31,640
don't actually know whether the areas

1102
00:49:36,100 --> 00:49:33,980
where we have progress or progress in a

1103
00:49:38,470 --> 00:49:36,110
direction that's leading us to something

1104
00:49:42,730 --> 00:49:38,480
we can put together into the schemes

1105
00:49:44,020 --> 00:49:42,740
that make the first prototype in and we

1106
00:49:46,150 --> 00:49:44,030
don't even know what the first

1107
00:49:48,580 --> 00:49:46,160
prototyping thing would look like so we

1108
00:49:50,650 --> 00:49:48,590
don't quite note and how do we know when

1109
00:49:52,930 --> 00:49:50,660
we're there we need to think about how

1110
00:49:54,550 --> 00:49:52,940
we know when we've reached there it's a

1111
00:49:56,680 --> 00:49:54,560
wonderful area it's the most interesting

1112
00:50:00,490 --> 00:49:56,690
area of science to me right now in

1113
00:50:13,480 --> 00:50:00,500

molecular terms and I'm glad thank you

1114
00:50:15,220 --> 00:50:13,490
for the invitation to be here so what if

1115
00:50:18,280 --> 00:50:15,230
we'll talk I think that polymers that

1116
00:50:20,260 --> 00:50:18,290
avoid the Leventhal paradox are probably

1117
00:50:21,280 --> 00:50:20,270
the most interesting ones to go after so

1118
00:50:23,080 --> 00:50:21,290
could you talk about the Leventhal

1119
00:50:25,860 --> 00:50:23,090
paradox let me tell you thank you so

1120
00:50:29,890 --> 00:50:25,870
much I mean I owe you a drink

1121
00:50:31,660 --> 00:50:29,900
smouldering the Leventhal paradox is

1122
00:50:33,460 --> 00:50:31,670
something which addresses the following

1123
00:50:35,860 --> 00:50:33,470
question it's very instructive to me and

1124
00:50:38,680 --> 00:50:35,870
it's what it teaches you look at a

1125
00:50:40,990 --> 00:50:38,690
protein and here's the sort of argument

1126
00:50:43,090 --> 00:50:41,000
then you say well maybe proteins were

1127
00:50:45,580 --> 00:50:43,100
evolved by randomly putting together

1128
00:50:47,770 --> 00:50:45,590
amino acids into pieces that became big

1129
00:50:50,140 --> 00:50:47,780
enough to be catalytically active just

1130
00:50:54,130 --> 00:50:50,150
put them together and let's take a

1131
00:50:56,350 --> 00:50:54,140
protein with 300 amino acids and do the

1132
00:50:58,900 --> 00:50:56,360
statistics and you take in the first

1133
00:51:00,940 --> 00:50:58,910
position you can put 20 amino acids I

1134
00:51:03,550 --> 00:51:00,950
mean I'm oversimplifying but 20 in the

1135
00:51:05,970 --> 00:51:03,560
second 20 and the third 20 so there

1136
00:51:08,740 --> 00:51:05,980
might be 22 3 hundreds of combinations

1137
00:51:10,870 --> 00:51:08,750
and then you do the experiment do the

1138
00:51:15,610 --> 00:51:10,880

experiment of making one molecule of

1139
00:51:17,440 --> 00:51:15,620
each of those 10 22 3 hundreds proteins

1140
00:51:19,510 --> 00:51:17,450
you pack them at a density of a crystal

1141
00:51:21,490 --> 00:51:19,520
and you ask how big is that piece

1142
00:51:24,670 --> 00:51:21,500
and that piece is bigger than the known

1143
00:51:27,520 --> 00:51:24,680
universe so whatever happened it wasn't

1144
00:51:30,130 --> 00:51:27,530
that and why that's interesting is that

1145
00:51:32,620 --> 00:51:30,140
it says there's another pathway through

1146
00:51:34,540 --> 00:51:32,630
this complicated phase space probably

1147
00:51:37,090 --> 00:51:34,550
you made little pieces maybe that formed

1148
00:51:38,920 --> 00:51:37,100
Gila Seas or foreign beta pleated sheet

1149
00:51:41,140 --> 00:51:38,930
like things and the pieces began to

1150
00:51:44,050 --> 00:51:41,150
aggregate some way and there was some

1151
00:51:46,330 --> 00:51:44,060
pathway by which evolution selected

1152
00:51:49,240 --> 00:51:46,340
along the way and I think looking for

1153
00:51:51,070 --> 00:51:49,250
those kinds of principles simply or

1154
00:51:53,140 --> 00:51:51,080
rather than saying look enough oceans

1155
00:51:55,780 --> 00:51:53,150
and enough billions of years and we'll

1156
00:51:57,370 --> 00:51:55,790
get there I think that won't work and we

1157
00:51:59,740 --> 00:51:57,380
don't know what the what the guiding

1158
00:52:05,110 --> 00:51:59,750
principles are is that satisfactory

1159
00:52:08,890 --> 00:52:05,120
answer what life does is to hydrogenate

1160
00:52:11,140 --> 00:52:08,900
carbon dioxide so that's its job and if

1161
00:52:12,820 --> 00:52:11,150
you take that diagram of yours with the

1162
00:52:15,490 --> 00:52:12,830
rush tag and find right in the middle

1163
00:52:17,890 --> 00:52:15,500

not only the krebs cycle or the radical

1164
00:52:19,420 --> 00:52:17,900
perhaps but also the acetyl coenzyme a

1165
00:52:21,700 --> 00:52:19,430
pathway that seems to be the initial

1166
00:52:23,910 --> 00:52:21,710
pathway and George Fuchs pointed out a

1167
00:52:28,000 --> 00:52:23,920
long time ago that gluconeogenesis

1168
00:52:30,250 --> 00:52:28,010
predate his glycolysis so if you build

1169
00:52:33,430 --> 00:52:30,260
everything up from co2 and hydrogen and

1170
00:52:35,530 --> 00:52:33,440
methane choice a and nitric oxide then

1171
00:52:37,450 --> 00:52:35,540
you can have a third spot at your table

1172
00:52:39,460 --> 00:52:37,460
for luncheon I think that's that's

1173
00:52:42,850 --> 00:52:39,470
probably true and I'm willing to take

1174
00:52:45,910 --> 00:52:42,860
anything that I can convince myself

1175
00:52:47,800 --> 00:52:45,920
could happen in primitive conditions now

1176
00:52:49,840 --> 00:52:47,810
one of the problems with hydrogen is

1177
00:52:52,750 --> 00:52:49,850
there were there certainly was hydrogen

1178
00:52:56,140 --> 00:52:52,760
in certain regions but not a lot of it

1179
00:53:03,340 --> 00:52:56,150
because it tended to play along and the

1180
00:53:05,860 --> 00:53:03,350
reduction of co2 what that's where we

1181
00:53:08,140 --> 00:53:05,870
get into this question of is that

1182
00:53:10,660 --> 00:53:08,150
concentration with that probability with

1183
00:53:12,280 --> 00:53:10,670
other things going on for a billion

1184
00:53:14,970 --> 00:53:12,290
years or however many years you want is

1185
00:53:22,510 --> 00:53:14,980
that enough and you accumulate products

1186
00:53:25,030 --> 00:53:22,520
sorry well I'm not actually arguing

1187
00:53:26,470 --> 00:53:25,040
because I don't know the answer all that

1188
00:53:28,780 --> 00:53:26,480

I'm saying is that if you look at the

1189
00:53:32,290 --> 00:53:28,790
pieces that you require to have the

1190
00:53:33,400 --> 00:53:32,300
whole thing go you have to have a number

1191
00:53:36,550 --> 00:53:33,410
of things happen in

1192
00:53:39,810 --> 00:53:36,560
come together and it's that coming

1193
00:53:42,130 --> 00:53:39,820
together apart and I have a problem with

1194
00:53:43,990 --> 00:53:42,140
that's why it wasn't chaos that's right

1195
00:53:46,270 --> 00:53:44,000
and if there are principles in that

1196
00:53:48,790 --> 00:53:46,280
which make it non chaotic which

1197
00:53:51,970 --> 00:53:48,800
organized themselves in a way that gives

1198
00:53:54,190 --> 00:53:51,980
us a sort of a pathway to self-assembly

1199
00:53:56,370 --> 00:53:54,200
then I think we've got a grip at that

1200
00:53:58,330 --> 00:53:56,380
point on what goes on and I'm

1201
00:54:27,010 --> 00:53:58,340
enthusiastic about anything that leads

1202
00:54:28,660 --> 00:54:27,020
in that direction I think you can make

1203
00:54:30,910 --> 00:54:28,670
amino acids I think you can even make

1204
00:54:33,760 --> 00:54:30,920
simple sugars what I don't see is how

1205
00:54:37,600 --> 00:54:33,770
you make a metabolic pathway and this

1206
00:54:39,580 --> 00:54:37,610
may be my lack of imagination or you

1207
00:54:40,990 --> 00:54:39,590
know cardiovascular all coming for REO

1208
00:54:42,970 --> 00:54:41,000
vascular disease but I just don't see

1209
00:54:45,280 --> 00:54:42,980
how you do it it's not in principle I

1210
00:54:47,410 --> 00:54:45,290
don't see in principle I see it's the

1211
00:54:49,300 --> 00:54:47,420
statistics and the probability of

1212
00:54:51,550 --> 00:54:49,310
putting it together in one place at one

1213
00:54:54,610 --> 00:54:51,560

time in such a fashion that it becomes

1214
00:54:56,590 --> 00:54:54,620
self-sustaining and so I'm I don't

1215
00:54:58,870 --> 00:54:56,600
disagree with the principle I just don't

1216
00:55:05,410 --> 00:54:58,880
see the experimental demonstration that

1217
00:55:08,350 --> 00:55:05,420
even suggest it could happen yeah I'm

1218
00:55:12,430 --> 00:55:08,360
not a chemist but I really enjoyed who

1219
00:55:16,540 --> 00:55:12,440
is here asking the question here ah oh

1220
00:55:19,360 --> 00:55:16,550
there yes I'm not chemist but I really

1221
00:55:21,970 --> 00:55:19,370
enjoyed the introduction it was very

1222
00:55:23,890 --> 00:55:21,980
thought-provoking but I wanted to return

1223
00:55:27,070 --> 00:55:23,900
to the slides that you showed where you

1224
00:55:29,380 --> 00:55:27,080
had some you had some chemical reactions

1225
00:55:31,180 --> 00:55:29,390
and you either could have a flatline or

1226
00:55:31,890 --> 00:55:31,190
you could have an oscillate oscillatory

1227
00:55:38,050 --> 00:55:31,900
behavior

1228
00:55:41,050 --> 00:55:38,060
periodic and it's bound right but the

1229
00:55:43,180 --> 00:55:41,060
nature of chaotic motion is that it is

1230
00:55:45,820 --> 00:55:43,190
you can have oscillations but they're

1231
00:55:47,200 --> 00:55:45,830
non periodic and the other thing is that

1232
00:55:50,050 --> 00:55:47,210
many chaotic system

1233
00:55:52,450 --> 00:55:50,060
are able to explore all face space and

1234
00:55:55,329 --> 00:55:52,460
these bound systems do not so the

1235
00:55:58,300 --> 00:55:55,339
question that I have is are you able to

1236
00:56:00,790 --> 00:55:58,310
produce in your laboratory some

1237
00:56:03,339 --> 00:56:00,800
reactions which you can classify as

1238
00:56:05,109 --> 00:56:03,349

chaotic for example you have oscillatory

1239
00:56:08,470 --> 00:56:05,119
behavior that doesn't have a fixed

1240
00:56:11,140 --> 00:56:08,480
periodicity and can perhaps then

1241
00:56:13,000 --> 00:56:11,150
eventually transform itself into some

1242
00:56:15,370 --> 00:56:13,010
sort of thing where it explores all

1243
00:56:17,800 --> 00:56:15,380
phase space that you give it that's a

1244
00:56:20,260 --> 00:56:17,810
really interesting question the answer

1245
00:56:21,910 --> 00:56:20,270
is that the answer is yes and no and

1246
00:56:23,950 --> 00:56:21,920
what I mean by that is that if you take

1247
00:56:27,220 --> 00:56:23,960
the system that's cleanly oscillating

1248
00:56:29,650 --> 00:56:27,230
and you do the laboratory experiment of

1249
00:56:33,250 --> 00:56:29,660
pushing it to the point where it's about

1250
00:56:35,589 --> 00:56:33,260
to undergo some bifurcation at that

1251
00:56:37,329 --> 00:56:35,599
point it becomes irregular you have this

1252
00:56:39,339 --> 00:56:37,339
phenomenon that you're probably very

1253
00:56:42,820 --> 00:56:39,349
familiar with known as critical slowing

1254
00:56:44,820 --> 00:56:42,830
down and the system other stuff starts

1255
00:56:47,380 --> 00:56:44,830
to happen and if you look at a typical

1256
00:56:50,290 --> 00:56:47,390
folded bifurcation in that dotted line

1257
00:56:52,300 --> 00:56:50,300
region you don't have stable state

1258
00:56:54,490 --> 00:56:52,310
condition this stable safe solutions

1259
00:56:57,010 --> 00:56:54,500
which means that any perturbation from

1260
00:56:59,500 --> 00:56:57,020
the outside flips it up or flips it down

1261
00:57:02,589 --> 00:56:59,510
which isn't exactly the same thing as

1262
00:57:04,540 --> 00:57:02,599
chaotic but it's non periodic I think

1263
00:57:07,180 --> 00:57:04,550

you can make that happen but I don't

1264
00:57:09,520 --> 00:57:07,190
think that that is truly chaos in the

1265
00:57:11,620 --> 00:57:09,530
sense that you're talking about it on

1266
00:57:13,329 --> 00:57:11,630
the other hand when you think about the

1267
00:57:15,880 --> 00:57:13,339
motion of something in us you know

1268
00:57:18,910 --> 00:57:15,890
cycling around this pathway trajectory

1269
00:57:21,250 --> 00:57:18,920
in a strange attractor system the stuff

1270
00:57:23,020 --> 00:57:21,260
that happens there is sometimes hard

1271
00:57:25,690 --> 00:57:23,030
it's hard to tell that you've actually

1272
00:57:27,910 --> 00:57:25,700
got an attractor of any sort as opposed

1273
00:57:29,260 --> 00:57:27,920
to a lot of random motion so I think

1274
00:57:30,790 --> 00:57:29,270
those are all the right kinds of

1275
00:57:34,570 --> 00:57:30,800
questions but I don't think we can

1276
00:57:36,880 --> 00:57:34,580
answer them yet with this system which

1277
00:57:38,410 --> 00:57:36,890
is why I say yes and no so I don't know

1278
00:57:42,460 --> 00:57:38,420
maybe I should have just said I don't

1279
00:57:45,160 --> 00:57:42,470
know there's so many really wonderful

1280
00:57:46,780 --> 00:57:45,170
tidbits in there but um the one point

1281
00:57:49,270 --> 00:57:46,790
that I wanted to make was when you were

1282
00:57:51,070 --> 00:57:49,280
talking about basically having the

1283
00:57:52,480 --> 00:57:51,080
inside of the cell stirred you know you

1284
00:57:54,490 --> 00:57:52,490
you were warned by your mother we

1285
00:57:56,710 --> 00:57:54,500
biologists warned that chemists only see

1286
00:57:58,780 --> 00:57:56,720
cells as bags of molecules rostering bar

1287
00:58:00,339 --> 00:57:58,790
but if you look at you know

1288
00:58:01,000 --> 00:58:00,349

well liking to me but you've got the gel

1289
00:58:03,190 --> 00:58:01,010
sauce today

1290
00:58:04,870 --> 00:58:03,200
any cell there's there's partitioning

1291
00:58:06,670 --> 00:58:04,880
and the more we learn about it the more

1292
00:58:08,470 --> 00:58:06,680
we see the partitioning and so I'm

1293
00:58:10,120 --> 00:58:08,480
wondering if you could buy it an awful

1294
00:58:11,860 --> 00:58:10,130
lot by starting to look at it as Eddie's

1295
00:58:17,530 --> 00:58:11,870
and currents and back waters rather than

1296
00:58:19,660 --> 00:58:17,540
a uniformly stirred again I would let me

1297
00:58:21,250 --> 00:58:19,670
say two things yes and no the the know

1298
00:58:24,130 --> 00:58:21,260
is that you don't have Eddie's and back

1299
00:58:26,230 --> 00:58:24,140
waters and something the size of a cell

1300
00:58:30,010 --> 00:58:26,240
because you just can't you can't get in

1301
00:58:31,870 --> 00:58:30,020
a momentum conserved that the momentum

1302
00:58:35,050 --> 00:58:31,880
doesn't allow you to have an eddy before

1303
00:58:37,240 --> 00:58:35,060
it's dissipated by by friction right but

1304
00:58:39,330 --> 00:58:37,250
on the other hand what you see in modern

1305
00:58:42,550 --> 00:58:39,340
cells as you see motors everywhere and

1306
00:58:44,200 --> 00:58:42,560
these motors everywhere we think of them

1307
00:58:46,600 --> 00:58:44,210
as carrying cargo but they probably

1308
00:58:48,580 --> 00:58:46,610
serve other functions as well so

1309
00:58:50,770 --> 00:58:48,590
actually the inside of a cell may well

1310
00:58:53,950 --> 00:58:50,780
be stirred more actively than we think

1311
00:58:55,960 --> 00:58:53,960
it's more than that I mean I promise you

1312
00:58:58,000 --> 00:58:55,970
carry oats but you would get enclosed

1313
00:58:59,710 --> 00:58:58,010

nuclei and so on which are you know like

1314
00:59:01,480 --> 00:58:59,720
rocks in a river right but you certainly

1315
00:59:03,970 --> 00:59:01,490
had things you know endoplasmic

1316
00:59:07,200 --> 00:59:03,980
reticulum so on even in the bacterium so

1317
00:59:09,880 --> 00:59:07,210
you don't get a uniform stirring so

1318
00:59:11,620 --> 00:59:09,890
palms you know pumping stuff out all

1319
00:59:13,300 --> 00:59:11,630
kinds of stuff is going on so I don't

1320
00:59:15,910 --> 00:59:13,310
think that we should think about the

1321
00:59:17,890 --> 00:59:15,920
inside of a cell in any sense as being a

1322
00:59:19,930 --> 00:59:17,900
stitch or drop of water and I think when

1323
00:59:21,760 --> 00:59:19,940
it works I think it works to our

1324
00:59:23,500 --> 00:59:21,770
advantage rather than anything else yes

1325
00:59:25,030 --> 00:59:23,510
we have a straight motor but it's not a

1326
00:59:27,040 --> 00:59:25,040
steering motor it's a gazillion little

1327
00:59:32,940 --> 00:59:27,050
perturbations that cause things to flop

1328
00:59:38,770 --> 00:59:32,950
around yeah yeah absolutely

1329
00:59:39,500 --> 00:59:38,780
absolutely I completely agree okay thank

1330
00:59:43,310 --> 00:59:39,510
you all

1331
01:00:02,030 --> 00:59:43,320
[Applause]