



BEYOND THE THERMODYNAMIC LIMIT: A TEMPLATE FOR SECOND LAW CHALLENGES

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SOCIETY
FOR
SCIENTIFIC
EXPLORATION

1
00:00:18,230 --> 00:00:15,829
among the many uh statements or

2
00:00:20,710 --> 00:00:18,240
endorsements of thermodynamics there are

3
00:00:22,870 --> 00:00:20,720
the top two or three one of them is by

4
00:00:25,750 --> 00:00:22,880
albert einstein and

5
00:00:27,349 --> 00:00:25,760
it reads classical thermodynamics is the

6
00:00:29,589 --> 00:00:27,359
only physical theory of universal

7
00:00:31,269 --> 00:00:29,599
content concerning which i am convinced

8
00:00:33,670 --> 00:00:31,279
that within the framework of

9
00:00:36,310 --> 00:00:33,680
applicability of its basic concepts

10
00:00:38,869 --> 00:00:36,320
it will never be overthrown

11
00:00:43,030 --> 00:00:38,879
now considering in particular the the

12
00:00:48,310 --> 00:00:46,069
what this says in other words is that

13
00:00:49,830 --> 00:00:48,320

thermodynamics is correct

14

00:00:51,110 --> 00:00:49,840

when it's correct

15

00:00:53,910 --> 00:00:51,120

and it isn't

16

00:00:58,869 --> 00:00:56,229

so this begs the question are there

17

00:01:01,590 --> 00:00:58,879

circumstances under which thermodynamics

18

00:01:03,750 --> 00:01:01,600

is not correct or not complete

19

00:01:05,350 --> 00:01:03,760

so with this in mind i'd like to

20

00:01:07,429 --> 00:01:05,360

introduce this talk

21

00:01:10,310 --> 00:01:07,439

beyond the thermodynamic limit a

22

00:01:12,950 --> 00:01:10,320

template for second law exceptions

23

00:01:15,590 --> 00:01:12,960

and i'm at the university of san diego

24

00:01:17,190 --> 00:01:15,600

not ucsd

25

00:01:18,550 --> 00:01:17,200

before we get started i'd like to

26
00:01:20,789 --> 00:01:18,560
acknowledge a number of people who made

27
00:01:22,950 --> 00:01:20,799
this possible charles chase of course

28
00:01:24,630 --> 00:01:22,960
and garrett medell and i'd also like to

29
00:01:26,230 --> 00:01:24,640
thank very much david miller my

30
00:01:28,149 --> 00:01:26,240
colleague here at the university who's

31
00:01:30,310 --> 00:01:28,159
been doing some wonderful experiments

32
00:01:31,510 --> 00:01:30,320
that some of which will be alluded to

33
00:01:33,670 --> 00:01:31,520
today

34
00:01:35,270 --> 00:01:33,680
i'd also like to thank fellaini and

35
00:01:38,630 --> 00:01:35,280
pasha thornton foundation for their

36
00:01:40,390 --> 00:01:38,640
generous support of this research

37
00:01:41,749 --> 00:01:40,400
the outline of this talk is

38
00:01:44,230 --> 00:01:41,759

fairly straightforward if you can

39

00:01:45,670 --> 00:01:44,240

consider it in a way a primer for the

40

00:01:47,830 --> 00:01:45,680

rest of the talks

41

00:01:49,190 --> 00:01:47,840

today concerning the second law

42

00:01:51,990 --> 00:01:49,200

the first thing i'd like to do is talk

43

00:01:54,389 --> 00:01:52,000

about the thermodynamic limit which is a

44

00:01:56,789 --> 00:01:54,399

technical term for an approximation

45

00:01:58,630 --> 00:01:56,799

that's often used in thermodynamics in

46

00:02:00,950 --> 00:01:58,640

order to get to results and then talk

47

00:02:03,030 --> 00:02:00,960

about how important boundaries are to

48

00:02:04,630 --> 00:02:03,040

real systems

49

00:02:05,990 --> 00:02:04,640

next i'd like to talk about the second

50

00:02:08,550 --> 00:02:06,000

law of renaissance that's occurred over

51
00:02:11,510 --> 00:02:08,560
the last 25 to 30 years which might also

52
00:02:13,190 --> 00:02:11,520
be called a second law revolution

53
00:02:14,949 --> 00:02:13,200
uh next i'd like to talk about one

54
00:02:17,190 --> 00:02:14,959
particular

55
00:02:19,030 --> 00:02:17,200
exception that's been found called

56
00:02:21,350 --> 00:02:19,040
epicatalysis which has been studied in

57
00:02:22,869 --> 00:02:21,360
laboratories here at the university here

58
00:02:24,869 --> 00:02:22,879
at the university of san diego for the

59
00:02:27,670 --> 00:02:24,879
last 25 years or so

60
00:02:29,270 --> 00:02:27,680
and finally from it infer a template for

61
00:02:30,229 --> 00:02:29,280
second law exceptions which appear to

62
00:02:31,990 --> 00:02:30,239
apply

63
00:02:33,430 --> 00:02:32,000

to all of them that are being discussed

64

00:02:35,509 --> 00:02:33,440

today and most

65

00:02:37,190 --> 00:02:35,519

in the literature

66

00:02:38,949 --> 00:02:37,200

finally i'd like to discuss

67

00:02:43,509 --> 00:02:38,959

ramifications and future future

68

00:02:47,830 --> 00:02:45,270

now to begin let's just kind of give a

69

00:02:50,470 --> 00:02:47,840

general definition of thermodynamics

70

00:02:52,710 --> 00:02:50,480

thermodynamics you can see has two words

71

00:02:55,110 --> 00:02:52,720

in it thermo and dynamic and that

72

00:02:58,229 --> 00:02:55,120

basically explains it it's the science

73

00:02:59,030 --> 00:02:58,239

of the interplay between heat and work

74

00:03:02,149 --> 00:02:59,040

and

75

00:03:05,270 --> 00:03:02,159

heat is microscopic motion so to speak

76

00:03:06,149 --> 00:03:05,280

and work is macroscopic motion

77

00:03:08,710 --> 00:03:06,159

so

78

00:03:09,509 --> 00:03:08,720

the thermodynamic limit however is

79

00:03:11,430 --> 00:03:09,519

um

80

00:03:13,750 --> 00:03:11,440

something more particular and this is an

81

00:03:16,149 --> 00:03:13,760

approximation that's used uh throughout

82

00:03:19,589 --> 00:03:16,159

the literature and it's basically this

83

00:03:21,030 --> 00:03:19,599

uh consider a box with n particles this

84

00:03:22,630 --> 00:03:21,040

can be arbitrary it's usually a very

85

00:03:25,830 --> 00:03:22,640

very large number

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00:03:26,710 --> 00:03:25,840

and a volume v given by this constant

87

00:03:29,270 --> 00:03:26,720

here

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00:03:31,270 --> 00:03:29,280

and let the number of particles go to

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00:03:33,270 --> 00:03:31,280

infinity and let the volume of the

90

00:03:35,830 --> 00:03:33,280

container go to infinity so both

91

00:03:38,229 --> 00:03:35,840

quantities n and v go to infinity but

92

00:03:40,789 --> 00:03:38,239

their ratio doesn't the ratio remains

93

00:03:42,710 --> 00:03:40,799

finite this is the number density

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00:03:47,110 --> 00:03:42,720

and

95

00:03:48,550 --> 00:03:47,120

assumption because what it allows you to

96

00:03:50,710 --> 00:03:48,560

do is

97

00:03:52,949 --> 00:03:50,720

make more easily calculations of things

98

00:03:55,030 --> 00:03:52,959

like specific heats and transport

99

00:03:57,190 --> 00:03:55,040

coefficients like diffusion

100

00:03:59,589 --> 00:03:57,200

latent heats

101
00:04:01,509 --> 00:03:59,599
all sorts of nice things so it's a

102
00:04:04,710 --> 00:04:01,519
standard approximation

103
00:04:07,350 --> 00:04:04,720
but it also brings in a kind of mindset

104
00:04:09,750 --> 00:04:07,360
into thermodynamics which is that

105
00:04:11,750 --> 00:04:09,760
boundaries are ignorable you can let the

106
00:04:13,190 --> 00:04:11,760
system just become infinite in size and

107
00:04:16,469 --> 00:04:13,200
forget about what the boundaries are

108
00:04:18,629 --> 00:04:16,479
doing and this is a dangerous assumption

109
00:04:19,830 --> 00:04:18,639
for as mark twain said what gets you

110
00:04:21,990 --> 00:04:19,840
into trouble

111
00:04:23,909 --> 00:04:22,000
is not what we don't know

112
00:04:26,310 --> 00:04:23,919
it's what we know for sure

113
00:04:27,670 --> 00:04:26,320

that just ain't so

114

00:04:30,550 --> 00:04:27,680

and it turns out

115

00:04:35,350 --> 00:04:30,560

that boundaries are not ignorable when

116

00:04:38,950 --> 00:04:37,270

so boundaries are what we interact with

117

00:04:40,870 --> 00:04:38,960

on an everyday basis when we touch

118

00:04:43,990 --> 00:04:40,880

things we're talking about boundaries

119

00:04:46,870 --> 00:04:44,000

when when water falls over a waterfall

120

00:04:48,790 --> 00:04:46,880

it it touches the rocks surfaces not the

121

00:04:51,110 --> 00:04:48,800

inside of the rocks

122

00:04:53,110 --> 00:04:51,120

boundaries are where the action really

123

00:04:54,710 --> 00:04:53,120

is in most of life

124

00:04:56,790 --> 00:04:54,720

and in fact

125

00:04:58,629 --> 00:04:56,800

many if not most of all the fields of

126

00:05:00,629 --> 00:04:58,639

physics are largely defined by their

127

00:05:03,830 --> 00:05:00,639

boundaries so for instance if you

128

00:05:08,629 --> 00:05:06,310

plasma has a sheath at the at its edge

129

00:05:09,590 --> 00:05:08,639

called the dubai sheath and in that

130

00:05:12,629 --> 00:05:09,600

sheath

131

00:05:14,950 --> 00:05:12,639

the plasma has very non-equilibrium

132

00:05:17,110 --> 00:05:14,960

characteristics to it it has a potential

133

00:05:19,029 --> 00:05:17,120

drop across it it has

134

00:05:20,790 --> 00:05:19,039

distribution functions

135

00:05:24,390 --> 00:05:20,800

for velocity which are

136

00:05:25,909 --> 00:05:24,400

non-linear non-maxwellian and these very

137

00:05:27,430 --> 00:05:25,919

strongly affect

138

00:05:28,870 --> 00:05:27,440

how the plasma interacts with the

139

00:05:30,870 --> 00:05:28,880

outside world

140

00:05:33,590 --> 00:05:30,880

if we look at semiconductors

141

00:05:36,150 --> 00:05:33,600

semiconductor devices like the pn diode

142

00:05:39,029 --> 00:05:36,160

which is kind of the starting point for

143

00:05:41,670 --> 00:05:39,039

our modern technology in electronics it

144

00:05:44,150 --> 00:05:41,680

consists of p-type and n-type silicon

145

00:05:45,670 --> 00:05:44,160

for instance which are differentially

146

00:05:47,670 --> 00:05:45,680

doped um

147

00:05:49,749 --> 00:05:47,680

silicon and they come together at a

148

00:05:52,390 --> 00:05:49,759

junction and that junction really

149

00:05:54,950 --> 00:05:52,400

matters for for making diodes and

150

00:05:57,510 --> 00:05:54,960

transistors and in this region called

151
00:06:00,469 --> 00:05:57,520
the depletion region where the p and n

152
00:06:05,510 --> 00:06:00,479
meet where the boundary of them is

153
00:06:09,990 --> 00:06:07,670
drop-offs and density you have strong

154
00:06:11,350 --> 00:06:10,000
electric fields lots and lots is

155
00:06:13,350 --> 00:06:11,360
happening here

156
00:06:15,430 --> 00:06:13,360
in chemistry almost everything in the

157
00:06:17,670 --> 00:06:15,440
room that you touched today will have

158
00:06:20,150 --> 00:06:17,680
been taught will have been touched by

159
00:06:21,749 --> 00:06:20,160
heterogeneous catalysis somewhere along

160
00:06:22,790 --> 00:06:21,759
its path in the production of the

161
00:06:23,510 --> 00:06:22,800
chemicals

162
00:06:26,790 --> 00:06:23,520
and

163
00:06:28,950 --> 00:06:26,800

a catalyst can is is a surface which

164

00:06:30,230 --> 00:06:28,960

interacts with molecules to create new

165

00:06:32,309 --> 00:06:30,240

products

166

00:06:34,230 --> 00:06:32,319

again it's the boundaries

167

00:06:36,070 --> 00:06:34,240

in biology which will be discussed later

168

00:06:36,870 --> 00:06:36,080

today by james lee

169

00:06:38,790 --> 00:06:36,880

um

170

00:06:41,189 --> 00:06:38,800

every every cell and many of its

171

00:06:43,350 --> 00:06:41,199

organelles have boundaries to them the

172

00:06:44,469 --> 00:06:43,360

membranes and these are very complex

173

00:06:48,150 --> 00:06:44,479

devices

174

00:06:50,309 --> 00:06:48,160

that uh assure that make possible life

175

00:06:53,029 --> 00:06:50,319

each one of these in fact each one of

176

00:06:55,189 --> 00:06:53,039

these four has been invoked in research

177

00:06:58,070 --> 00:06:55,199

at the university of san diego

178

00:06:59,749 --> 00:06:58,080

and among the roughly one dozen or so

179

00:07:04,710 --> 00:06:59,759

second law challenges that we've put

180

00:07:08,629 --> 00:07:06,790

as has been said

181

00:07:10,550 --> 00:07:08,639

god made the bulk

182

00:07:13,749 --> 00:07:10,560

the devil made the surface and the

183

00:07:18,469 --> 00:07:16,309

boundaries well just by their mere

184

00:07:20,950 --> 00:07:18,479

existence they indicate some sort of

185

00:07:22,390 --> 00:07:20,960

broken physical or chemical symmetry in

186

00:07:24,870 --> 00:07:22,400

the system

187

00:07:27,909 --> 00:07:24,880

they are discontinuities in chemical

188

00:07:30,070 --> 00:07:27,919

potential pressure or temperature

189

00:07:31,670 --> 00:07:30,080

and because are discontinuities and

190

00:07:33,270 --> 00:07:31,680

things like chemical potentials they're

191

00:07:35,510 --> 00:07:33,280

automatically

192

00:07:36,790 --> 00:07:35,520

reservoirs of free energy

193

00:07:39,270 --> 00:07:36,800

and they also

194

00:07:41,350 --> 00:07:39,280

in effect represent a metastable state

195

00:07:42,950 --> 00:07:41,360

because true equilibrium would be a

196

00:07:45,270 --> 00:07:42,960

complete smearing out of all particles

197

00:07:46,950 --> 00:07:45,280

to uniform density and temperature

198

00:07:48,950 --> 00:07:46,960

and whenever you have a boundary that

199

00:07:51,510 --> 00:07:48,960

simply is not the case so if you wait

200

00:07:53,510 --> 00:07:51,520

long enough any boundary will erase and

201
00:07:55,670 --> 00:07:53,520
disappear so it never really was an

202
00:08:00,070 --> 00:07:55,680
equilibrium state they're metastable

203
00:08:03,749 --> 00:08:01,990
now if you have

204
00:08:05,110 --> 00:08:03,759
thermodynamic properties

205
00:08:06,869 --> 00:08:05,120
on a boundary they're usually more

206
00:08:08,950 --> 00:08:06,879
complex than the bulk

207
00:08:10,550 --> 00:08:08,960
and they also present opportunities for

208
00:08:12,390 --> 00:08:10,560
work extraction

209
00:08:14,629 --> 00:08:12,400
and some of these surfaces some of these

210
00:08:17,029 --> 00:08:14,639
boundaries actually

211
00:08:19,589 --> 00:08:17,039
some allow for cyclic work extraction

212
00:08:21,749 --> 00:08:19,599
derived from ambient single temperature

213
00:08:24,150 --> 00:08:21,759

thermal energy and that mouthful

214

00:08:28,390 --> 00:08:24,160

basically means you can challenge or

215

00:08:31,189 --> 00:08:29,189

now

216

00:08:33,269 --> 00:08:31,199

to put this into perspective

217

00:08:36,149 --> 00:08:33,279

the second law has been

218

00:08:38,949 --> 00:08:36,159

undergoing really unprecedented scrutiny

219

00:08:40,630 --> 00:08:38,959

over the last 25 to 30 years

220

00:08:43,029 --> 00:08:40,640

roughly three to four dozen closer to

221

00:08:44,630 --> 00:08:43,039

four dozen second law challenges have

222

00:08:47,590 --> 00:08:44,640

have reached into the scientific

223

00:08:49,670 --> 00:08:47,600

literature since the 1990s

224

00:08:51,670 --> 00:08:49,680

60 to 80 articles are in the refereed

225

00:08:54,389 --> 00:08:51,680

scientific literature and there are more

226

00:08:56,710 --> 00:08:54,399

of these in the last 25 years

227

00:08:59,269 --> 00:08:56,720

than there have been in the last 170

228

00:09:01,110 --> 00:08:59,279

years of the history of the second law

229

00:09:02,710 --> 00:09:01,120

it's been a revolution it's a

230

00:09:04,630 --> 00:09:02,720

renaissance there's been a technical

231

00:09:06,949 --> 00:09:04,640

monograph published by springer on the

232

00:09:09,269 --> 00:09:06,959

subject and international conferences

233

00:09:11,990 --> 00:09:09,279

held for the first time

234

00:09:13,670 --> 00:09:12,000

and so things are changing not maybe

235

00:09:16,389 --> 00:09:13,680

quickly enough for those of us in the

236

00:09:18,389 --> 00:09:16,399

field but nonetheless they're changing

237

00:09:19,590 --> 00:09:18,399

and you can see it in the progression of

238

00:09:22,470 --> 00:09:19,600

the second law of challenges that have

239

00:09:24,230 --> 00:09:22,480

arisen over the last 25 years or so what

240

00:09:26,310 --> 00:09:24,240

i would call generation one would be the

241

00:09:28,070 --> 00:09:26,320

first 15 years or so and most of the

242

00:09:30,470 --> 00:09:28,080

challenges at that point were

243

00:09:31,990 --> 00:09:30,480

theoretical in nature they were

244

00:09:34,630 --> 00:09:32,000

thought experiments

245

00:09:36,550 --> 00:09:34,640

mostly they were in extreme uh physical

246

00:09:38,550 --> 00:09:36,560

regimes like very high temperatures or

247

00:09:41,350 --> 00:09:38,560

very low temperatures purely quantum

248

00:09:42,470 --> 00:09:41,360

systems large gravitating objects things

249

00:09:44,790 --> 00:09:42,480

like that

250

00:09:46,630 --> 00:09:44,800

and there were only a handful a few

251
00:09:47,509 --> 00:09:46,640
corroborating experiments of the basic

252
00:09:53,990 --> 00:09:47,519
process

253
00:09:56,310 --> 00:09:54,000
generation 2 from 2005 2015 there was

254
00:09:58,470 --> 00:09:56,320
more theory but stronger experimental

255
00:10:00,470 --> 00:09:58,480
support stronger corroboratory evidence

256
00:10:02,870 --> 00:10:00,480
that something might be amiss

257
00:10:04,550 --> 00:10:02,880
and even a few patterns

258
00:10:06,310 --> 00:10:04,560
generation three which is what we're in

259
00:10:09,110 --> 00:10:06,320
right now and which will be discussed

260
00:10:11,030 --> 00:10:09,120
more fully during uh during today

261
00:10:13,269 --> 00:10:11,040
has more diversity

262
00:10:15,509 --> 00:10:13,279
more room temperature and pressure more

263
00:10:16,829 --> 00:10:15,519

uh everyday accessible types of second

264

00:10:20,470 --> 00:10:16,839

law challenges

265

00:10:23,190 --> 00:10:20,480

and many i shouldn't say many several

266

00:10:24,470 --> 00:10:23,200

confirmation experiments

267

00:10:26,710 --> 00:10:24,480

what i'm looking forward to is

268

00:10:28,470 --> 00:10:26,720

generation four which would be the

269

00:10:30,870 --> 00:10:28,480

second law of challenges or second law

270

00:10:33,030 --> 00:10:30,880

devices which are commercialized and

271

00:10:36,710 --> 00:10:33,040

this may be perhaps in the next several

272

00:10:40,310 --> 00:10:39,269

so when it comes to generation three

273

00:10:42,389 --> 00:10:40,320

these are

274

00:10:44,829 --> 00:10:42,399

experiments or ideas that in principle

275

00:10:48,069 --> 00:10:44,839

or have been experimentally

276

00:10:49,910 --> 00:10:48,079

tested um later today paul thibodeau

277

00:10:52,949 --> 00:10:49,920

will be talking about his graphene

278

00:10:55,269 --> 00:10:52,959

trampoline and um extractions of of

279

00:10:57,670 --> 00:10:55,279

current from that thermionic emitters

280

00:10:58,470 --> 00:10:57,680

from germano de bruyne uh brahmo

281

00:11:01,030 --> 00:10:58,480

um

282

00:11:02,949 --> 00:11:01,040

some similar work of this in plasma

283

00:11:04,870 --> 00:11:02,959

systems was done at the university here

284

00:11:07,910 --> 00:11:04,880

back in the 1990s

285

00:11:10,550 --> 00:11:07,920

uh cell membranes by james lee

286

00:11:11,750 --> 00:11:10,560

the casmir cavity hot electron system by

287

00:11:14,069 --> 00:11:11,760

garrett

288

00:11:16,069 --> 00:11:14,079

this one is it's not confirmed that it's

289

00:11:19,430 --> 00:11:16,079

a second law device uh some of us think

290

00:11:21,990 --> 00:11:19,440

so garrett is uh is weighing um multiple

291

00:11:24,310 --> 00:11:22,000

possibilities very open-mindedly

292

00:11:25,829 --> 00:11:24,320

and um at the university here we've

293

00:11:28,630 --> 00:11:25,839

looked at roughly a dozen over the last

294

00:11:30,150 --> 00:11:28,640

25 years and falling into multiple

295

00:11:32,310 --> 00:11:30,160

categories

296

00:11:34,069 --> 00:11:32,320

listed here we'll be taking a look at

297

00:11:39,350 --> 00:11:34,079

the last one which is probably the most

298

00:11:43,509 --> 00:11:41,110

so let's talk a little bit about the

299

00:11:45,430 --> 00:11:43,519

second law um

300

00:11:47,670 --> 00:11:45,440

we understand the second law it's really

301

00:11:49,430 --> 00:11:47,680

a kind of an intuitive

302

00:11:51,269 --> 00:11:49,440

in an intuitive way we feel it in our

303

00:11:53,030 --> 00:11:51,279

bones we find in almost everything we

304

00:11:54,870 --> 00:11:53,040

do the second law has been called the

305

00:11:56,790 --> 00:11:54,880

supreme law of nature

306

00:11:59,110 --> 00:11:56,800

by arthur eddington

307

00:12:00,949 --> 00:11:59,120

90 years ago because it applies to

308

00:12:02,069 --> 00:12:00,959

almost everything

309

00:12:04,870 --> 00:12:02,079

and we

310

00:12:06,949 --> 00:12:04,880

see it in the fact that cars need gas

311

00:12:09,190 --> 00:12:06,959

houses need heating and cooling

312

00:12:11,350 --> 00:12:09,200

appliances need electricity industry

313

00:12:14,230 --> 00:12:11,360

needs power we need food and we have to

314

00:12:16,310 --> 00:12:14,240

constantly resupply things everything

315

00:12:18,150 --> 00:12:16,320

needs an energy supply because otherwise

316

00:12:21,430 --> 00:12:18,160

it simply runs down

317

00:12:23,430 --> 00:12:21,440

and this has become is because work gets

318

00:12:26,790 --> 00:12:23,440

transformed into heat

319

00:12:29,110 --> 00:12:26,800

things get messier

320

00:12:31,670 --> 00:12:29,120

at the microscopic level you can see

321

00:12:33,110 --> 00:12:31,680

this as the transition of order into

322

00:12:35,829 --> 00:12:33,120

disorder

323

00:12:38,150 --> 00:12:35,839

organized energy which you'd call work

324

00:12:39,829 --> 00:12:38,160

is in the form of electrical

325

00:12:42,230 --> 00:12:39,839

power coming out of the wall kinetic

326

00:12:45,110 --> 00:12:42,240

energy of things like cars gravitational

327

00:12:47,110 --> 00:12:45,120

potential energy of water in a in a dam

328

00:12:49,590 --> 00:12:47,120

chemical energy which keeps us alive and

329

00:12:52,710 --> 00:12:49,600

runs our cars nuclear energy and all

330

00:12:55,509 --> 00:12:52,720

this organized energy gets ultimately or

331

00:12:58,310 --> 00:12:55,519

largely transformed into

332

00:13:01,590 --> 00:12:58,320

disorganized energy thermal energy heat

333

00:13:03,910 --> 00:13:01,600

microscopic motion from the second law

334

00:13:07,269 --> 00:13:03,920

you can see this as a transition from

335

00:13:09,750 --> 00:13:07,279

low entropy to high entropy states

336

00:13:11,670 --> 00:13:09,760

from high quality energy degraded into

337

00:13:13,750 --> 00:13:11,680

low quality energy

338

00:13:14,870 --> 00:13:13,760

and this occurs and the second law can

339

00:13:17,190 --> 00:13:14,880

be seen

340

00:13:19,509 --> 00:13:17,200

from the smallest processes in nature at

341

00:13:21,910 --> 00:13:19,519

nuclear levels all the way up to the

342

00:13:25,430 --> 00:13:21,920

ultimate fate of the cosmos so indeed

343

00:13:27,190 --> 00:13:25,440

it's a wide-ranging law

344

00:13:29,110 --> 00:13:27,200

now the second law itself does not have

345

00:13:31,190 --> 00:13:29,120

a single statement there are lots of

346

00:13:34,790 --> 00:13:31,200

different forms of it in the book that

347

00:13:36,710 --> 00:13:34,800

vladi kept and i wrote back in 2005 we

348

00:13:39,430 --> 00:13:36,720

accumulated 21 different versions of the

349

00:13:41,030 --> 00:13:39,440

second law we found in the literature

350

00:13:42,629 --> 00:13:41,040

and among them the

351

00:13:44,310 --> 00:13:42,639

probably the most prominent are are

352

00:13:45,990 --> 00:13:44,320

these

353

00:13:48,470 --> 00:13:46,000

the first the kelvin ponch form of the

354

00:13:50,310 --> 00:13:48,480

second law heat cannot be transformed

355

00:13:52,550 --> 00:13:50,320

solely into work in a thermodynamic

356

00:13:54,710 --> 00:13:52,560

cycle that means that you can't

357

00:13:56,230 --> 00:13:54,720

reorganize the disorder

358

00:13:58,150 --> 00:13:56,240

at the microscopic level into

359

00:13:59,829 --> 00:13:58,160

macroscopic order again without paying

360

00:14:00,629 --> 00:13:59,839

price

361

00:14:04,949 --> 00:14:00,639

and

362

00:14:07,590 --> 00:14:04,959

goes back to the age of the steam engine

363

00:14:09,189 --> 00:14:07,600

1850.

364

00:14:11,750 --> 00:14:09,199

the one by max planck is probably the

365

00:14:13,590 --> 00:14:11,760

second most famous entropy or disorder

366

00:14:15,509 --> 00:14:13,600

never decreases for any spontaneous

367

00:14:17,430 --> 00:14:15,519

natural process

368

00:14:19,430 --> 00:14:17,440

and then the clausius form which also

369

00:14:21,189 --> 00:14:19,440

goes back 150 years

370

00:14:23,269 --> 00:14:21,199

heat goes from hot to cold not vice

371

00:14:25,350 --> 00:14:23,279

versa and this is what you see hot

372

00:14:28,790 --> 00:14:25,360

objects cool down

373

00:14:30,790 --> 00:14:28,800

cold objects don't spontaneously heat up

374

00:14:32,230 --> 00:14:30,800

perpetual motion machines are impossible

375

00:14:35,030 --> 00:14:32,240

there are no perfect heat engines

376

00:14:38,069 --> 00:14:35,040

refrigerators or anything else

377

00:14:38,949 --> 00:14:38,079

all natural processes are irreversible

378

00:14:40,870 --> 00:14:38,959

and

379

00:14:43,110 --> 00:14:40,880

these statements can be you know

380

00:14:44,550 --> 00:14:43,120

summarized in some informal ones like

381

00:14:46,790 --> 00:14:44,560

murphy's law

382

00:14:49,430 --> 00:14:46,800

um if anything can go wrong it will and

383

00:14:51,590 --> 00:14:49,440

its corollaries things like situations

384

00:14:53,189 --> 00:14:51,600

tend to progress from bad to worse

385

00:14:55,269 --> 00:14:53,199

the only way to deal with a can of worms

386

00:14:56,870 --> 00:14:55,279

is to find a bigger can

387

00:14:58,629 --> 00:14:56,880

and then there's the existential form of

388

00:15:00,310 --> 00:14:58,639

the second law

389

00:15:02,710 --> 00:15:00,320

we're all going to die

390

00:15:04,069 --> 00:15:02,720

and this is largely mediated by the

391

00:15:06,150 --> 00:15:04,079

second law

392

00:15:08,949 --> 00:15:06,160

on the other hand the fact that time

393

00:15:10,629 --> 00:15:08,959

goes forward the fact that things happen

394

00:15:12,710 --> 00:15:10,639

is due to the second law the

395

00:15:15,910 --> 00:15:12,720

irreversibility of the universe gives us

396

00:15:17,590 --> 00:15:15,920

its charm and gives life its taste so

397

00:15:20,310 --> 00:15:17,600

although it'll kill us in the end the

398

00:15:22,310 --> 00:15:20,320

second law is really the means by which

399

00:15:26,470 --> 00:15:22,320

time goes forward and things happen so

400

00:15:31,430 --> 00:15:28,310

but what is the nature of physical law i

401
00:15:33,350 --> 00:15:31,440
think people have a can often have a mis

402
00:15:35,269 --> 00:15:33,360
misunderstanding of what of what

403
00:15:37,269 --> 00:15:35,279
physical laws are

404
00:15:39,350 --> 00:15:37,279
many scientists actually believe the

405
00:15:40,790 --> 00:15:39,360
second law can be proven

406
00:15:42,629 --> 00:15:40,800
and that's not true

407
00:15:45,670 --> 00:15:42,639
from a purely epistemological point of

408
00:15:47,670 --> 00:15:45,680
view you can't prove a physical law

409
00:15:49,189 --> 00:15:47,680
it's an axiom

410
00:15:52,150 --> 00:15:49,199
of science

411
00:15:53,509 --> 00:15:52,160
and axioms by their very nature cannot

412
00:15:56,069 --> 00:15:53,519
be proved

413
00:15:58,310 --> 00:15:56,079

if you could prove the second law

414

00:16:00,069 --> 00:15:58,320

for more fundamental ideas those would

415

00:16:01,670 --> 00:16:00,079

be the laws because if you prove

416

00:16:02,550 --> 00:16:01,680

something it's a theorem

417

00:16:05,030 --> 00:16:02,560

so

418

00:16:06,710 --> 00:16:05,040

the second law cannot be proven it's

419

00:16:08,550 --> 00:16:06,720

simply

420

00:16:09,749 --> 00:16:08,560

believed because it's observed to be

421

00:16:11,350 --> 00:16:09,759

true

422

00:16:12,629 --> 00:16:11,360

but that also means that it's

423

00:16:16,069 --> 00:16:12,639

provisional

424

00:16:17,030 --> 00:16:16,079

it's true only absolutely true only

425

00:16:19,269 --> 00:16:17,040

because

426

00:16:21,590 --> 00:16:19,279

it is observed to be absolutely true and

427

00:16:24,550 --> 00:16:21,600

a single exception to that

428

00:16:26,870 --> 00:16:24,560

would not destroy its usefulness per se

429

00:16:29,509 --> 00:16:26,880

but simply destroy its inviolability and

430

00:16:31,910 --> 00:16:29,519

open up possibilities

431

00:16:33,829 --> 00:16:31,920

most laws that we have that you look at

432

00:16:35,910 --> 00:16:33,839

in the literature are in fact

433

00:16:37,990 --> 00:16:35,920

rules of thumb they are not absolute

434

00:16:40,629 --> 00:16:38,000

although they are quite useful

435

00:16:42,470 --> 00:16:40,639

the ideal gas law for instance well

436

00:16:44,710 --> 00:16:42,480

it sounds like it's ideal and it sounds

437

00:16:46,790 --> 00:16:44,720

like a law but in fact it assumes

438

00:16:48,389 --> 00:16:46,800

point-like particles

439

00:16:51,749 --> 00:16:48,399

that are non-interactive and that's not

440

00:16:53,189 --> 00:16:51,759

true of real gases so you might want to

441

00:16:55,509 --> 00:16:53,199

do something like the van der waals

442

00:16:57,430 --> 00:16:55,519

equation instead which updates it a bit

443

00:16:58,629 --> 00:16:57,440

but still is not exact

444

00:17:00,710 --> 00:16:58,639

so

445

00:17:02,829 --> 00:17:00,720

there are they're creating a perfectly

446

00:17:05,429 --> 00:17:02,839

true gas law is probably almost

447

00:17:08,069 --> 00:17:05,439

impossible universal's

448

00:17:10,390 --> 00:17:08,079

newton's universal law of gravitation

449

00:17:11,990 --> 00:17:10,400

well it's really good for everyday

450

00:17:13,829 --> 00:17:12,000

gravitational dynamics and good enough

451

00:17:15,429 --> 00:17:13,839

for nasa for the most part

452

00:17:18,230 --> 00:17:15,439

but we know that the general theory of

453

00:17:20,150 --> 00:17:18,240

relativity by einstein itself supersedes

454

00:17:22,390 --> 00:17:20,160

newton's universal law of gravitation

455

00:17:23,750 --> 00:17:22,400

and is a more exact description of

456

00:17:25,590 --> 00:17:23,760

nature

457

00:17:27,029 --> 00:17:25,600

moreover

458

00:17:29,510 --> 00:17:27,039

the general theory of relativity is

459

00:17:31,270 --> 00:17:29,520

thought to be an approximation itself

460

00:17:33,990 --> 00:17:31,280

there might be something more underlying

461

00:17:36,549 --> 00:17:34,000

it for instance quantum gravity

462

00:17:39,029 --> 00:17:36,559

hubble's law of which describes the

463

00:17:41,029 --> 00:17:39,039

distance velocity relationship for

464

00:17:42,630 --> 00:17:41,039

distant galaxies

465

00:17:45,350 --> 00:17:42,640

is not true for distances less than

466

00:17:47,110 --> 00:17:45,360

maybe 50 to 100 million light years and

467

00:17:49,590 --> 00:17:47,120

furthermore when you when you throw in

468

00:17:50,710 --> 00:17:49,600

something like uh dark energy it's not

469

00:17:53,190 --> 00:17:50,720

really true

470

00:17:54,390 --> 00:17:53,200

so hubble's law is gonna again just a

471

00:17:56,070 --> 00:17:54,400

rule of thumb

472

00:17:57,510 --> 00:17:56,080

the law of natural selection another

473

00:18:00,390 --> 00:17:57,520

example

474

00:18:01,830 --> 00:18:00,400

most so-called laws have limits of

475

00:18:04,310 --> 00:18:01,840

applicability

476

00:18:06,630 --> 00:18:04,320

and so it's quite reasonable to assume

477

00:18:10,150 --> 00:18:06,640

that the second law does as well after

478

00:18:12,070 --> 00:18:10,160

all it was discovered 170 years ago

479

00:18:13,510 --> 00:18:12,080

in the age of steam engines and since

480

00:18:14,950 --> 00:18:13,520

then we've had

481

00:18:17,190 --> 00:18:14,960

all sorts of new kinds of energy

482

00:18:19,510 --> 00:18:17,200

discovered we've had special relativity

483

00:18:21,590 --> 00:18:19,520

quantum mechanics chaos syrian and other

484

00:18:24,310 --> 00:18:21,600

revolutions as well so there's no reason

485

00:18:28,230 --> 00:18:24,320

to expect the second law to be absolute

486

00:18:30,390 --> 00:18:28,240

although it is terribly useful

487

00:18:33,270 --> 00:18:30,400

so with that i'd like to introduce

488

00:18:34,230 --> 00:18:33,280

the concept of epicatalysis which is an

489

00:18:37,270 --> 00:18:34,240

area

490

00:18:40,710 --> 00:18:37,280

which is a form of catalysis so to speak

491

00:18:42,230 --> 00:18:40,720

that challenges the second law

492

00:18:44,310 --> 00:18:42,240

so let's kind of review first of all

493

00:18:45,990 --> 00:18:44,320

what catalysts do

494

00:18:47,830 --> 00:18:46,000

catalysts are

495

00:18:49,350 --> 00:18:47,840

usually are assumed to have three

496

00:18:51,590 --> 00:18:49,360

properties

497

00:18:53,110 --> 00:18:51,600

first is that they speed up chemical

498

00:18:54,870 --> 00:18:53,120

reactions

499

00:18:57,270 --> 00:18:54,880

next they're not consumed by the

500

00:18:59,110 --> 00:18:57,280

reaction that they speed up

501
00:19:01,750 --> 00:18:59,120
and third

502
00:19:05,190 --> 00:19:01,760
they don't change the final equilibrium

503
00:19:07,270 --> 00:19:05,200
of the reaction that they enter into

504
00:19:10,870 --> 00:19:07,280
so let's consider a simple reaction

505
00:19:14,230 --> 00:19:10,880
where we have a diatomic molecule a_2

506
00:19:17,270 --> 00:19:14,240
in equilibrium with its monomers so the

507
00:19:20,310 --> 00:19:17,280
diatomic a_2 disassociates into two

508
00:19:21,510 --> 00:19:20,320
monomers $2a$ and those can recombine back

509
00:19:24,549 --> 00:19:21,520
into a_2

510
00:19:26,549 --> 00:19:24,559
and in a closed system with with walls

511
00:19:30,710 --> 00:19:26,559
and gas phase equilibrium you would you

512
00:19:32,470 --> 00:19:30,720
have a particular gas phase equilibrium

513
00:19:34,950 --> 00:19:32,480

but when you get into a situation where

514

00:19:37,029 --> 00:19:34,960

the mean free path of your gas is long

515

00:19:38,630 --> 00:19:37,039

compared to the size of the cavity and

516

00:19:40,630 --> 00:19:38,640

that you have chemical reactivity of

517

00:19:43,190 --> 00:19:40,640

that gas with the walls

518

00:19:45,270 --> 00:19:43,200

then the third principle of catalysis

519

00:19:46,390 --> 00:19:45,280

which says that the equilibrium is

520

00:19:48,310 --> 00:19:46,400

unique

521

00:19:50,950 --> 00:19:48,320

is not true anymore

522

00:19:53,669 --> 00:19:50,960

for instance if we consider two surfaces

523

00:19:56,549 --> 00:19:53,679

s_2 and s_1 these are two different

524

00:19:59,350 --> 00:19:56,559

surfaces let's say this is

525

00:20:01,029 --> 00:19:59,360

made out of rhenium and the s_1 is made

526

00:20:03,350 --> 00:20:01,039

out of tungsten

527

00:20:06,310 --> 00:20:03,360

and let's say we have hydrogen

528

00:20:08,549 --> 00:20:06,320

molecules in atoms if two atoms come in

529

00:20:11,110 --> 00:20:08,559

they can recombine to form a the

530

00:20:13,190 --> 00:20:11,120

diatomic species and if the diatomic

531

00:20:15,510 --> 00:20:13,200

species comes in it can just sit around

532

00:20:17,990 --> 00:20:15,520

and then just leave as the diatomic

533

00:20:21,909 --> 00:20:18,000

species again so you have recombination

534

00:20:26,870 --> 00:20:24,070

s1 on the other hand can have a reaction

535

00:20:29,350 --> 00:20:26,880

with the surface such that the monomers

536

00:20:32,149 --> 00:20:29,360

come in and leave without much without

537

00:20:34,950 --> 00:20:32,159

much trouble but the diatomic molecule

538

00:20:39,350 --> 00:20:34,960

comes in and is split

539

00:20:41,270 --> 00:20:39,360

and disassociates into two a atoms

540

00:20:43,669 --> 00:20:41,280

this phenomena has been noted for well

541

00:20:45,110 --> 00:20:43,679

over 100 years with hydrogen hydrogen

542

00:20:47,350 --> 00:20:45,120

reacting with high temperature

543

00:20:48,630 --> 00:20:47,360

refractory metals like tungsten rhenium

544

00:20:50,549 --> 00:20:48,640

molybdenum

545

00:20:52,390 --> 00:20:50,559

tantalum and iridium

546

00:20:53,909 --> 00:20:52,400

are have been known to disassociate

547

00:20:55,750 --> 00:20:53,919

hydrogen at

548

00:20:57,669 --> 00:20:55,760

at different rates but no one ever

549

00:20:59,350 --> 00:20:57,679

really thought to think what that really

550

00:21:04,230 --> 00:20:59,360

means

551
00:21:06,870 --> 00:21:04,240
if one surface is preferentially

552
00:21:09,110 --> 00:21:06,880
recombining

553
00:21:11,909 --> 00:21:09,120
monomers into dimers

554
00:21:14,630 --> 00:21:11,919
the bond energy is liberated into the

555
00:21:16,710 --> 00:21:14,640
surface and it begins to heat

556
00:21:19,669 --> 00:21:16,720
conversely if you have a surface which

557
00:21:21,029 --> 00:21:19,679
preferentially disassociates molecules

558
00:21:23,350 --> 00:21:21,039
into atoms

559
00:21:26,070 --> 00:21:23,360
it has to provide the

560
00:21:28,470 --> 00:21:26,080
um the bond energy energy

561
00:21:32,149 --> 00:21:28,480
to break that bond and as a result it

562
00:21:36,230 --> 00:21:34,070
so under these circumstances you can

563
00:21:39,350 --> 00:21:36,240

imagine the following scenario

564

00:21:41,270 --> 00:21:39,360

two surfaces surface two and surface one

565

00:21:43,029 --> 00:21:41,280

inside a cavity such that the mean free

566

00:21:44,950 --> 00:21:43,039

path is long and the molecules interact

567

00:21:47,270 --> 00:21:44,960

with the surfaces and don't interact

568

00:21:49,350 --> 00:21:47,280

with each other in the gas phase such

569

00:21:51,350 --> 00:21:49,360

that they simply go from surface to

570

00:21:53,510 --> 00:21:51,360

surface for the most most part

571

00:21:55,909 --> 00:21:53,520

on surface one you have disassociation

572

00:21:59,190 --> 00:21:55,919

on surface two you have recombination as

573

00:22:01,110 --> 00:21:59,200

a result s2 heats s1 cools and now you

574

00:22:02,950 --> 00:22:01,120

have a temperature difference

575

00:22:05,029 --> 00:22:02,960

that temperature difference then can be

576

00:22:06,390 --> 00:22:05,039

used to drive a classical heat engine

577

00:22:08,470 --> 00:22:06,400

where heat from the high temperature

578

00:22:09,909 --> 00:22:08,480

reservoir goes through the resin goes

579

00:22:14,230 --> 00:22:09,919

through the heat engine

580

00:22:16,390 --> 00:22:14,240

creates work performs work and

581

00:22:18,390 --> 00:22:16,400

excess heat goes back to the cold

582

00:22:19,510 --> 00:22:18,400

reservoir and this can continue in

583

00:22:21,590 --> 00:22:19,520

principle

584

00:22:22,789 --> 00:22:21,600

indefinitely because this temperature

585

00:22:25,430 --> 00:22:22,799

differential

586

00:22:27,110 --> 00:22:25,440

is quote originally an equilibrium state

587

00:22:29,350 --> 00:22:27,120

of the system

588

00:22:32,310 --> 00:22:29,360

this is what's called an epicalytic

589

00:22:36,070 --> 00:22:34,070

in real in real life you might be able

590

00:22:38,070 --> 00:22:36,080

to exploit this temperature differential

591

00:22:40,149 --> 00:22:38,080

by putting in a thermoelectric generator

592

00:22:43,830 --> 00:22:40,159

between the two surfaces and export

593

00:22:47,510 --> 00:22:45,909

now the idea of epicalysis was

594

00:22:49,990 --> 00:22:47,520

controversial since it was first put

595

00:22:52,230 --> 00:22:50,000

forward because it was understood that

596

00:22:53,590 --> 00:22:52,240

it could lead to a second law of

597

00:22:55,510 --> 00:22:53,600

violation

598

00:22:57,270 --> 00:22:55,520

experiments have been conducted now

599

00:22:59,350 --> 00:22:57,280

which verify the existence of

600

00:23:03,110 --> 00:22:59,360

epicalysis

601
00:23:05,590 --> 00:23:03,120
can be found in a number of papers in

602
00:23:07,909 --> 00:23:05,600
physical review and elsewhere

603
00:23:10,789 --> 00:23:07,919
and experiments were performed back in

604
00:23:13,350 --> 00:23:10,799
2013 and 2014 which

605
00:23:15,590 --> 00:23:13,360
uh verified or strongly i would say

606
00:23:17,029 --> 00:23:15,600
verify but this might say corroborate

607
00:23:19,350 --> 00:23:17,039
this phenomenon

608
00:23:23,350 --> 00:23:19,360
and the way it works is this

609
00:23:24,549 --> 00:23:23,360
the experiments are conducted in a

610
00:23:27,190 --> 00:23:24,559
high vacuum

611
00:23:28,149 --> 00:23:27,200
vacuum vessel and inside of it one one

612
00:23:29,909 --> 00:23:28,159
puts

613
00:23:34,149 --> 00:23:29,919

a black body

614

00:23:37,190 --> 00:23:34,159

closed container that has one

615

00:23:39,430 --> 00:23:37,200

temperature in it and the temperature of

616

00:23:41,750 --> 00:23:39,440

this black body cylinder can be changed

617

00:23:43,750 --> 00:23:41,760

by passing current through this through

618

00:23:46,149 --> 00:23:43,760

the metallic walls and that can heat it

619

00:23:47,830 --> 00:23:46,159

up ohmically like a heat like a filament

620

00:23:50,390 --> 00:23:47,840

and a light bulb

621

00:23:52,390 --> 00:23:50,400

inside of it and going now to the the

622

00:23:54,390 --> 00:23:52,400

far right diagram this is the inside of

623

00:23:55,990 --> 00:23:54,400

the cavity current passes through the

624

00:23:58,789 --> 00:23:56,000

walls the walls are made out of either

625

00:24:02,070 --> 00:23:58,799

tungsten or rhenium both work

626
00:24:04,070 --> 00:24:02,080
and inside you have two filaments these

627
00:24:07,669 --> 00:24:04,080
are actually thermocouples one coated

628
00:24:10,230 --> 00:24:07,679
with rhenium one coated with tungsten

629
00:24:13,269 --> 00:24:10,240
the experiments which describe this

630
00:24:14,149 --> 00:24:13,279
are in foundations of physics

631
00:24:16,470 --> 00:24:14,159
now

632
00:24:18,070 --> 00:24:16,480
when the walls the walls temperature can

633
00:24:20,470 --> 00:24:18,080
be varied from room temperature up to

634
00:24:23,430 --> 00:24:20,480
about two thousand kelvin

635
00:24:27,510 --> 00:24:23,440
and um when you heat up the walls

636
00:24:29,269 --> 00:24:27,520
at in a good vacuum or high vacuum

637
00:24:31,350 --> 00:24:29,279
you find that the two thermocouples

638
00:24:32,870 --> 00:24:31,360

register the same temperature as you

639

00:24:34,630 --> 00:24:32,880

would expect they're inside the same

640

00:24:36,630 --> 00:24:34,640

container and therefore they should come

641

00:24:39,029 --> 00:24:36,640

to the same temperature so in a vacuum

642

00:24:40,710 --> 00:24:39,039

they come to the same temperature

643

00:24:43,110 --> 00:24:40,720

now when you put in

644

00:24:46,230 --> 00:24:43,120

helium which is a

645

00:24:48,789 --> 00:24:46,240

an inert noble gas again they come

646

00:24:51,269 --> 00:24:48,799

exactly to the same temperatures which

647

00:24:53,990 --> 00:24:51,279

is what you'd expect

648

00:24:55,510 --> 00:24:54,000

but then if you put in hydrogen

649

00:24:56,549 --> 00:24:55,520

at the same pressures you'd put in the

650

00:24:59,430 --> 00:24:56,559

helium

651
00:25:02,870 --> 00:24:59,440
the temperatures of these diverge

652
00:25:05,110 --> 00:25:02,880
greatly up to over 125 degrees kelvin

653
00:25:06,230 --> 00:25:05,120
difference at pressures on the order of

654
00:25:07,669 --> 00:25:06,240
a few torr

655
00:25:09,590 --> 00:25:07,679
and the reason is

656
00:25:11,909 --> 00:25:09,600
rhenium breaks down

657
00:25:14,870 --> 00:25:11,919
uranium

658
00:25:17,350 --> 00:25:14,880
recombines hydrogen better than tungsten

659
00:25:19,029 --> 00:25:17,360
does and as a result it cools the

660
00:25:21,430 --> 00:25:19,039
tungsten heat

661
00:25:22,870 --> 00:25:21,440
and the power unit area difference in

662
00:25:26,390 --> 00:25:22,880
terms of

663
00:25:28,630 --> 00:25:26,400

the order of a tenth of a megawatt per

664

00:25:31,190 --> 00:25:28,640

square meter these devices of course are

665

00:25:32,789 --> 00:25:31,200

quite small and so the the power

666

00:25:34,470 --> 00:25:32,799

differences between the two are got not

667

00:25:37,350 --> 00:25:34,480

very much but in terms of

668

00:25:39,110 --> 00:25:37,360

surface area it is quite substantial

669

00:25:41,669 --> 00:25:39,120

this is repeatable the temperature

670

00:25:43,269 --> 00:25:41,679

difference remains until the hydrogen is

671

00:25:45,510 --> 00:25:43,279

taken out

672

00:25:47,669 --> 00:25:45,520

and this demonstrates that in a single

673

00:25:50,149 --> 00:25:47,679

black body cavity you can achieve two

674

00:25:52,230 --> 00:25:50,159

separate temperatures this would be like

675

00:25:55,590 --> 00:25:52,240

in your own room right now having a

676
00:25:57,590 --> 00:25:55,600
block of ice and a hot cup of coffee

677
00:26:00,149 --> 00:25:57,600
coffee's staying hot forever

678
00:26:02,310 --> 00:26:00,159
and the ice never melting that's second

679
00:26:06,390 --> 00:26:02,320
law simply does not allow for that but

680
00:26:09,909 --> 00:26:07,750
now because this experiment was

681
00:26:11,909 --> 00:26:09,919
conducted at very low pressures and at

682
00:26:13,350 --> 00:26:11,919
very high temperatures no one has

683
00:26:15,669 --> 00:26:13,360
repeated it

684
00:26:17,350 --> 00:26:15,679
and since it's since these original

685
00:26:19,669 --> 00:26:17,360
experiments our laboratory has been

686
00:26:21,909 --> 00:26:19,679
looking for evidence of not high

687
00:26:24,310 --> 00:26:21,919
temperature epicalysis but room

688
00:26:27,269 --> 00:26:24,320

temperature epicalysis and some early

689

00:26:29,830 --> 00:26:27,279

experiments back in 2015 suggested very

690

00:26:33,029 --> 00:26:29,840

strongly that that hydrogen bonded

691

00:26:36,310 --> 00:26:33,039

dimers like formic acid could create

692

00:26:38,149 --> 00:26:36,320

room temperature epicalysis

693

00:26:39,990 --> 00:26:38,159

and so as kind of an update or i should

694

00:26:41,830 --> 00:26:40,000

say a postscript

695

00:26:43,750 --> 00:26:41,840

we have done those experiments now

696

00:26:45,669 --> 00:26:43,760

looking for temperature differentials

697

00:26:47,669 --> 00:26:45,679

and these experiments were were

698

00:26:50,870 --> 00:26:47,679

conducted by my colleague

699

00:26:52,710 --> 00:26:50,880

david miller he's done a wonderful job

700

00:26:55,029 --> 00:26:52,720

and in the last two weeks we have found

701
00:26:57,830 --> 00:26:55,039
very very strong evidence for room

702
00:26:59,430 --> 00:26:57,840
temperature epicatalysis with sizable

703
00:27:02,070 --> 00:26:59,440
temperature differentials between

704
00:27:04,789 --> 00:27:02,080
polymer surfaces interacting with formic

705
00:27:09,510 --> 00:27:06,789
the power densities potentially

706
00:27:11,990 --> 00:27:09,520
available in epicatalytic thermal diodes

707
00:27:13,990 --> 00:27:12,000
have been calculated analytically and

708
00:27:15,430 --> 00:27:14,000
through numerical simulation found to be

709
00:27:17,350 --> 00:27:15,440
substantial

710
00:27:19,990 --> 00:27:17,360
in principle the power densities could

711
00:27:21,669 --> 00:27:20,000
be as high as 100 megawatts per cubic

712
00:27:23,350 --> 00:27:21,679
meter but of course that cannot be

713
00:27:26,070 --> 00:27:23,360

attained because if you're going to get

714

00:27:28,389 --> 00:27:26,080

power from an etd that requires turning

715

00:27:31,430 --> 00:27:28,399

heat into work and you have to supply

716

00:27:33,510 --> 00:27:31,440

the etd with thermal energy and that's

717

00:27:36,070 --> 00:27:33,520

going to be limited by how fast you can

718

00:27:37,510 --> 00:27:36,080

you can send that energy in and so this

719

00:27:39,510 --> 00:27:37,520

kind of power density will not be

720

00:27:41,110 --> 00:27:39,520

attainable except for brief moments

721

00:27:42,470 --> 00:27:41,120

before the system freezes itself to

722

00:27:44,710 --> 00:27:42,480

death

723

00:27:46,630 --> 00:27:44,720

but its uses well the power the the

724

00:27:49,350 --> 00:27:46,640

power that you get out of the etd could

725

00:27:51,430 --> 00:27:49,360

be used for basically any form of work

726

00:27:54,070 --> 00:27:51,440

that you would normally want to use it

727

00:27:57,269 --> 00:27:54,080

for heating and cooling directly thermal

728

00:28:01,190 --> 00:27:57,279

electricity freezing or boiling water

729

00:28:03,590 --> 00:28:01,200

so the etd is a is a

730

00:28:08,710 --> 00:28:03,600

instantiation of a second law

731

00:28:13,750 --> 00:28:10,710

and it suggests

732

00:28:14,950 --> 00:28:13,760

by example conditions for second law

733

00:28:15,750 --> 00:28:14,960

exceptions

734

00:28:18,389 --> 00:28:15,760

and

735

00:28:21,029 --> 00:28:18,399

i would like to to pose

736

00:28:22,549 --> 00:28:21,039

or propose the following

737

00:28:24,630 --> 00:28:22,559

the the conditions for a second law

738

00:28:27,029 --> 00:28:24,640

exception would probably involve these

739

00:28:29,430 --> 00:28:27,039

five characteristics first of all some

740

00:28:31,669 --> 00:28:29,440

sort of finite or bounded system in

741

00:28:33,669 --> 00:28:31,679

other words one that does not adhere to

742

00:28:35,590 --> 00:28:33,679

the mindset at least of the

743

00:28:38,470 --> 00:28:35,600

thermodynamic limbic in other words

744

00:28:40,470 --> 00:28:38,480

taking boundaries seriously

745

00:28:42,789 --> 00:28:40,480

number two there should be a thermally

746

00:28:45,110 --> 00:28:42,799

regenerable energy reservoir that's

747

00:28:47,430 --> 00:28:45,120

something you could express as kt

748

00:28:50,310 --> 00:28:47,440

boltzmann's constant times temperature

749

00:28:52,310 --> 00:28:50,320

that's at one or more of the boundaries

750

00:28:54,230 --> 00:28:52,320

next you need to have a physical or

751
00:28:56,950 --> 00:28:54,240
thermodynamic asymmetry built into the

752
00:28:58,789 --> 00:28:56,960
system you need an independent so to

753
00:29:01,110 --> 00:28:58,799
speak orthogonal work extraction

754
00:29:04,230 --> 00:29:01,120
apparatus that's independent of the of

755
00:29:06,630 --> 00:29:04,240
the energy reservoir

756
00:29:07,909 --> 00:29:06,640
and fifth you need to have a some sort

757
00:29:12,389 --> 00:29:07,919
of

758
00:29:14,389 --> 00:29:12,399
metastable configuration for your system

759
00:29:18,149 --> 00:29:14,399
another another way in other words a way

760
00:29:18,870 --> 00:29:18,159
to reset the thermal reservoir of um of

761
00:29:20,630 --> 00:29:18,880
the

762
00:29:22,789 --> 00:29:20,640
device

763
00:29:26,070 --> 00:29:22,799

so let's look at these in terms of the

764

00:29:27,830 --> 00:29:26,080

etd the epically thermal diode it's

765

00:29:28,630 --> 00:29:27,840

certainly a finite inbounded system

766

00:29:30,310 --> 00:29:28,640

check

767

00:29:32,630 --> 00:29:30,320

the thermally regenerable energy

768

00:29:33,750 --> 00:29:32,640

reservoir at the boundary

769

00:29:40,470 --> 00:29:33,760

is

770

00:29:43,269 --> 00:29:40,480

monomer a and the dimer a₂ these the

771

00:29:45,190 --> 00:29:43,279

bond energy and breaking um and

772

00:29:47,669 --> 00:29:45,200

recombining it is the source of your

773

00:29:49,750 --> 00:29:47,679

energy reservoir at the boundary

774

00:29:52,230 --> 00:29:49,760

the physical thermodynamic asymmetry

775

00:29:54,789 --> 00:29:52,240

that's built into this particular system

776

00:29:56,230 --> 00:29:54,799

are s1 and s2 these two surfaces have

777

00:29:59,350 --> 00:29:56,240

different chemical activities with

778

00:30:00,870 --> 00:29:59,360

respect to a and a2

779

00:30:01,990 --> 00:30:00,880

the independent work extraction

780

00:30:03,909 --> 00:30:02,000

apparatus well it could be the

781

00:30:05,269 --> 00:30:03,919

thermoelectric system that we talked

782

00:30:07,990 --> 00:30:05,279

about earlier

783

00:30:09,830 --> 00:30:08,000

switchable and resettable

784

00:30:12,630 --> 00:30:09,840

aspect of it comes about because of the

785

00:30:14,870 --> 00:30:12,640

gas cycling between the two surfaces and

786

00:30:17,269 --> 00:30:14,880

the walls

787

00:30:19,669 --> 00:30:17,279

so all of these these five

788

00:30:21,029 --> 00:30:19,679

characteristics are met by the etd and

789

00:30:24,710 --> 00:30:21,039

it turns out

790

00:30:26,470 --> 00:30:24,720

they are met by all the dozen or so uh

791

00:30:29,669 --> 00:30:26,480

second law challenges that have been

792

00:30:32,149 --> 00:30:29,679

promoted at the university of san diego

793

00:30:34,230 --> 00:30:32,159

and furthermore i would argue that they

794

00:30:36,470 --> 00:30:34,240

are these five characteristics can be

795

00:30:38,630 --> 00:30:36,480

seen in each of the generation three

796

00:30:41,590 --> 00:30:38,640

second law exceptions that are being

797

00:30:42,870 --> 00:30:41,600

that can um that are being described by

798

00:30:43,669 --> 00:30:42,880

um

799

00:30:48,630 --> 00:30:43,679

the

800

00:30:53,510 --> 00:30:48,640

ask or maybe challenge you to try to

801
00:30:58,389 --> 00:30:55,350
so what does this mean

802
00:31:00,549 --> 00:30:58,399
what what a second law device does if

803
00:31:03,029 --> 00:31:00,559
it's if it violates the second law in a

804
00:31:05,350 --> 00:31:03,039
in a way that that

805
00:31:06,870 --> 00:31:05,360
extracts work so to speak from from the

806
00:31:09,110 --> 00:31:06,880
heat bath

807
00:31:09,990 --> 00:31:09,120
you can call it a heat recycler

808
00:31:14,710 --> 00:31:10,000
so

809
00:31:15,990 --> 00:31:14,720
car or tv a heater a computer lights

810
00:31:17,990 --> 00:31:16,000
whatever you wish

811
00:31:20,230 --> 00:31:18,000
it generates a lot of waste heat all the

812
00:31:22,870 --> 00:31:20,240
energy you've paid for in your life 99

813
00:31:25,029 --> 00:31:22,880

of it is turned into heat probably more

814

00:31:27,190 --> 00:31:25,039

and after that you can't use it again

815

00:31:29,269 --> 00:31:27,200

but a heat recycler takes that heat and

816

00:31:31,669 --> 00:31:29,279

turns it back into work

817

00:31:33,830 --> 00:31:31,679

so if you form this cycle between the

818

00:31:36,070 --> 00:31:33,840

system and the heat recycler you've

819

00:31:38,630 --> 00:31:36,080

basically turned heat not into a

820

00:31:41,190 --> 00:31:38,640

sustainable form of energy and not into

821

00:31:43,430 --> 00:31:41,200

a just a green form of energy or a

822

00:31:45,350 --> 00:31:43,440

renewable form of energy you have turned

823

00:31:47,669 --> 00:31:45,360

it into a recyclable

824

00:31:49,269 --> 00:31:47,679

form of energy it's a completely

825

00:31:51,430 --> 00:31:49,279

different mindset when it comes to

826

00:31:54,070 --> 00:31:51,440

energy your system creates heat your

827

00:31:55,909 --> 00:31:54,080

heat recycler creates work and they work

828

00:31:57,110 --> 00:31:55,919

together such that you have a closed

829

00:31:58,870 --> 00:31:57,120

system

830

00:32:01,909 --> 00:31:58,880

so you don't need to

831

00:32:05,029 --> 00:32:01,919

get energy energy from elsewhere because

832

00:32:10,070 --> 00:32:07,269

so to give you an idea of how much

833

00:32:12,549 --> 00:32:10,080

thermal energy or heat is around us on

834

00:32:14,870 --> 00:32:12,559

an everyday basis consider a cubic meter

835

00:32:17,269 --> 00:32:14,880

of air and your room you're in may have

836

00:32:19,269 --> 00:32:17,279

several hundred cubic meters

837

00:32:22,070 --> 00:32:19,279

each cubic meter of air in terms of just

838

00:32:24,389 --> 00:32:22,080

the kinetic energy of the molecules

839

00:32:26,070 --> 00:32:24,399

oxygen and nitrogen corresponds to

840

00:32:31,029 --> 00:32:26,080

roughly the chemical energy of

841

00:32:33,190 --> 00:32:31,039

detonating 60 grams of tnt

842

00:32:35,830 --> 00:32:33,200

a cubic meter of water if you were to

843

00:32:38,389 --> 00:32:35,840

take it from 20 degrees c down to 0

844

00:32:40,230 --> 00:32:38,399

degrees c and form ice

845

00:32:42,149 --> 00:32:40,240

the amount of energy that that you could

846

00:32:43,430 --> 00:32:42,159

extract from that cubic meter of water

847

00:32:47,029 --> 00:32:43,440

would be equivalent to about 100

848

00:32:48,549 --> 00:32:47,039

kilograms of tnt over 200 pounds of tnt

849

00:32:50,710 --> 00:32:48,559

so literally we are living in an

850

00:32:53,830 --> 00:32:50,720

environment just with thermal energy

851
00:32:56,070 --> 00:32:53,840
alone we're just swimming in energy and

852
00:32:58,149 --> 00:32:56,080
because of the second law up till now we

853
00:33:00,870 --> 00:32:58,159
can't get at it

854
00:33:02,549 --> 00:33:00,880
but if we could with heat recyclers if

855
00:33:04,870 --> 00:33:02,559
you were to take the atmosphere ocean

856
00:33:06,950 --> 00:33:04,880
and upper crust and consider simply the

857
00:33:09,590 --> 00:33:06,960
amount of thermal energy available there

858
00:33:11,590 --> 00:33:09,600
it would be roughly 10 000 times

859
00:33:13,269 --> 00:33:11,600
the fossil fuel

860
00:33:15,110 --> 00:33:13,279
the chemical energy of all the fossil

861
00:33:19,110 --> 00:33:15,120
fuel reserves in the world

862
00:33:20,470 --> 00:33:19,120
and if in fact heat is truly recyclable

863
00:33:22,630 --> 00:33:20,480

then because you can constantly

864

00:33:24,549 --> 00:33:22,640

recyclable recycle it and use it again

865

00:33:26,149 --> 00:33:24,559

and again the energy supplies are

866

00:33:29,269 --> 00:33:26,159

virtually infinite

867

00:33:33,029 --> 00:33:31,509

so what are the ramifications of of such

868

00:33:34,710 --> 00:33:33,039

devices well

869

00:33:37,990 --> 00:33:34,720

certainly energy would would change its

870

00:33:40,549 --> 00:33:38,000

character from being one from work being

871

00:33:43,750 --> 00:33:40,559

simply being lost in the form of heat to

872

00:33:45,750 --> 00:33:43,760

making energy recyclable um heat itself

873

00:33:48,630 --> 00:33:45,760

is ubiquitous it's free it's clean it's

874

00:33:51,110 --> 00:33:48,640

green and effectively inexhaustible

875

00:33:52,950 --> 00:33:51,120

energy itself though represents 10 of

876

00:33:55,190 --> 00:33:52,960

the world's economy

877

00:33:58,310 --> 00:33:55,200

and if you were to and if you were to

878

00:34:01,509 --> 00:33:58,320

suddenly so to speak change that uh

879

00:34:03,350 --> 00:34:01,519

energy equation that energy uh ecology

880

00:34:04,870 --> 00:34:03,360

that we have in our economy lots of

881

00:34:07,190 --> 00:34:04,880

things would change you would have

882

00:34:10,470 --> 00:34:07,200

economic disruptions you would have

883

00:34:12,149 --> 00:34:10,480

industrial changes in a massive scale

884

00:34:13,750 --> 00:34:12,159

you would probably have geopolitical

885

00:34:15,510 --> 00:34:13,760

upheaval as well

886

00:34:16,869 --> 00:34:15,520

but you'd also have lots of ecological

887

00:34:19,510 --> 00:34:16,879

benefits

888

00:34:21,829 --> 00:34:19,520

this form of energy does not produce

889

00:34:24,389 --> 00:34:21,839

co2 or other greenhouse gases except in

890

00:34:25,909 --> 00:34:24,399

the production of the devices themselves

891

00:34:27,589 --> 00:34:25,919

you don't have to tear up the land to

892

00:34:29,510 --> 00:34:27,599

get to the coal or drill holes in the

893

00:34:31,430 --> 00:34:29,520

ground you won't have oil spills there

894

00:34:32,629 --> 00:34:31,440

will be all sorts of ecological benefits

895

00:34:34,790 --> 00:34:32,639

for it

896

00:34:37,349 --> 00:34:34,800

literally energy makes the world go

897

00:34:39,909 --> 00:34:37,359

round in every sense of the word

898

00:34:42,790 --> 00:34:39,919

in the sense physically chemically

899

00:34:44,629 --> 00:34:42,800

thermodynamically ecologically

900

00:34:47,270 --> 00:34:44,639

um economically

901
00:34:49,430 --> 00:34:47,280
geopolitically militarily energy is the

902
00:34:51,589 --> 00:34:49,440
currency of change and if you change the

903
00:34:54,869 --> 00:34:51,599
fundamental relationship of ourselves to

904
00:34:56,550 --> 00:34:54,879
energy you change all of those things

905
00:34:57,670 --> 00:34:56,560
i think it would be actually quite

906
00:35:00,390 --> 00:34:57,680
useful

907
00:35:02,550 --> 00:35:00,400
now before things truly get underway

908
00:35:04,790 --> 00:35:02,560
to consider what the world would be like

909
00:35:07,109 --> 00:35:04,800
if energy were truly democratized if

910
00:35:09,030 --> 00:35:07,119
energy no longer cost anything aside

911
00:35:10,870 --> 00:35:09,040
from the devices that were to extract it

912
00:35:13,910 --> 00:35:10,880
directly from the environment how would

913
00:35:15,349 --> 00:35:13,920

that change the um things like the use

914

00:35:17,750 --> 00:35:15,359

of the power grid

915

00:35:19,829 --> 00:35:17,760

the the um

916

00:35:22,150 --> 00:35:19,839

the ecology and economy of the world all

917

00:35:23,589 --> 00:35:22,160

of these things would would change but i

918

00:35:25,670 --> 00:35:23,599

to my knowledge this has never really

919

00:35:27,270 --> 00:35:25,680

been considered in a serious manner i

920

00:35:28,870 --> 00:35:27,280

think a good time to do that would be

921

00:35:31,109 --> 00:35:28,880

now

922

00:35:33,430 --> 00:35:31,119

because as generation three goes to

923

00:35:35,589 --> 00:35:33,440

generation four devices from the

924

00:35:38,470 --> 00:35:35,599

experiment from the lab

925

00:35:40,870 --> 00:35:38,480

to the commercial realm um things will

926

00:35:43,190 --> 00:35:40,880

change and this will typically if one

927

00:35:45,430 --> 00:35:43,200

looks at history take 30 to 40 years

928

00:35:47,349 --> 00:35:45,440

once once commercial devices are created

929

00:35:48,710 --> 00:35:47,359

that's how long new technologies

930

00:35:50,950 --> 00:35:48,720

typically take

931

00:35:52,870 --> 00:35:50,960

but it could be on an accelerated

932

00:35:54,470 --> 00:35:52,880

time scale if

933

00:35:57,270 --> 00:35:54,480

if given the emergency in the

934

00:36:01,670 --> 00:35:58,950

so in summary

935

00:36:03,589 --> 00:36:01,680

um the second law if one looks hard at

936

00:36:04,630 --> 00:36:03,599

it straight ahead there are experiments

937

00:36:07,109 --> 00:36:04,640

now which

938

00:36:09,670 --> 00:36:07,119

uh violate certain certain versions of

939

00:36:11,990 --> 00:36:09,680

the second law you know and can be taken

940

00:36:13,670 --> 00:36:12,000

therefore as violating the second law

941

00:36:15,990 --> 00:36:13,680

and that all of them

942

00:36:19,030 --> 00:36:16,000

involve some sort of boundary free

943

00:36:20,470 --> 00:36:19,040

energy source this seems to be a key um

944

00:36:22,390 --> 00:36:20,480

aspect of it

945

00:36:24,150 --> 00:36:22,400

there are half a dozen such second law

946

00:36:25,349 --> 00:36:24,160

experiments currently in progress around

947

00:36:26,630 --> 00:36:25,359

the world

948

00:36:28,790 --> 00:36:26,640

and

949

00:36:31,270 --> 00:36:28,800

i believe generation 4 devices are on

950

00:36:32,790 --> 00:36:31,280

the horizon

951

00:36:34,150 --> 00:36:32,800

i'd like to end this talk with a couple

952

00:36:36,069 --> 00:36:34,160

of things the first is what is

953

00:36:38,790 --> 00:36:36,079

considered probably to be the most

954

00:36:41,349 --> 00:36:38,800

famous of all second law endorsements by

955

00:36:43,109 --> 00:36:41,359

arthur eddington who was a scientist

956

00:36:44,710 --> 00:36:43,119

who was really as famous as einstein in

957

00:36:46,790 --> 00:36:44,720

the early 20th century

958

00:36:49,829 --> 00:36:46,800

and over 90 years ago

959

00:36:51,829 --> 00:36:49,839

he um he said what is often used as the

960

00:36:54,790 --> 00:36:51,839

um as the main justification for

961

00:36:57,030 --> 00:36:54,800

considering the second law absolute

962

00:36:59,109 --> 00:36:57,040

the law that entropy always increases

963

00:37:01,349 --> 00:36:59,119

the second law of thermodynamics holds i

964

00:37:02,790 --> 00:37:01,359

think the supreme position among laws of

965

00:37:04,310 --> 00:37:02,800

nature

966

00:37:05,589 --> 00:37:04,320

if someone points out to you that your

967

00:37:07,750 --> 00:37:05,599

pet theory of the universe is in

968

00:37:09,270 --> 00:37:07,760

disagreement with maxwell's equation

969

00:37:10,310 --> 00:37:09,280

then so much the worse for maxwell's

970

00:37:11,589 --> 00:37:10,320

equation

971

00:37:14,069 --> 00:37:11,599

if it is found to be

972

00:37:16,710 --> 00:37:14,079

contradicted by observation well these

973

00:37:17,990 --> 00:37:16,720

experimentalists fungal things sometimes

974

00:37:20,069 --> 00:37:18,000

but if your theory is found to be

975

00:37:22,550 --> 00:37:20,079

against the second law of thermodynamics

976
00:37:24,950 --> 00:37:22,560
i can give you no hope there is nothing

977
00:37:27,349 --> 00:37:24,960
for it but to collapse in deepest

978
00:37:29,030 --> 00:37:27,359
humiliation

979
00:37:29,990 --> 00:37:29,040
i think the time has passed

980
00:37:32,470 --> 00:37:30,000
for

981
00:37:34,069 --> 00:37:32,480
such fundamentalist statements of faith

982
00:37:35,750 --> 00:37:34,079
concerning the second law

983
00:37:37,670 --> 00:37:35,760
and i think it's time to consider new

984
00:37:40,069 --> 00:37:37,680
formulations of the second law for

985
00:37:42,069 --> 00:37:40,079
instance one something like this

986
00:37:45,829 --> 00:37:42,079
for any spontaneous process the entropy

987
00:37:55,349 --> 00:37:48,310
except when it does

988
00:38:02,310 --> 00:37:56,390

thank you

989

00:38:06,230 --> 00:38:02,320

uh to the field to

990

00:38:07,430 --> 00:38:06,240

this symposium and uh to your

991

00:38:10,790 --> 00:38:07,440

results

992

00:38:13,190 --> 00:38:10,800

uh one of the fascinating

993

00:38:14,550 --> 00:38:13,200

things for me has been how daniel has

994

00:38:15,829 --> 00:38:14,560

been publishing

995

00:38:17,589 --> 00:38:15,839

evidence

996

00:38:18,390 --> 00:38:17,599

for violations

997

00:38:19,589 --> 00:38:18,400

for

998

00:38:22,950 --> 00:38:19,599

years

999

00:38:24,710 --> 00:38:22,960

and that evidence has been met in the

1000

00:38:27,030 --> 00:38:24,720

scientific literature

1001
00:38:28,550 --> 00:38:27,040
with silence

1002
00:38:30,630 --> 00:38:28,560
and uh

1003
00:38:32,150 --> 00:38:30,640
maybe today is a

1004
00:38:33,829 --> 00:38:32,160
will be will mark a little bit of a

1005
00:38:38,870 --> 00:38:33,839
change there

1006
00:38:43,109 --> 00:38:41,589
yes uh thank you um

1007
00:38:45,030 --> 00:38:43,119
uh professor sheehan i think this is

1008
00:38:47,670 --> 00:38:45,040
probably one of the most important uh

1009
00:38:51,030 --> 00:38:47,680
presentations in this symposium or uh

1010
00:38:53,190 --> 00:38:51,040
many others um i really appreciate that

1011
00:38:54,310 --> 00:38:53,200
uh i have only uh two questions try to

1012
00:38:56,710 --> 00:38:54,320
keep it

1013
00:38:59,190 --> 00:38:56,720

short amongst many others uh one is sort

1014

00:39:01,190 --> 00:38:59,200

of a metaphysical and the other is uh

1015

00:39:03,030 --> 00:39:01,200

more practical the metaphysical question

1016

00:39:06,150 --> 00:39:03,040

is uh you had mentioned that

1017

00:39:08,310 --> 00:39:06,160

um time goes forward because of the

1018

00:39:10,950 --> 00:39:08,320

second law um

1019

00:39:14,550 --> 00:39:10,960

this may be a take a long answer but

1020

00:39:18,230 --> 00:39:14,560

have you written anything on that uh

1021

00:39:21,030 --> 00:39:18,240

issue uh apart from um uh pure physical

1022

00:39:24,230 --> 00:39:21,040

uh article or physics articles

1023

00:39:26,470 --> 00:39:24,240

and my second question is um given that

1024

00:39:30,150 --> 00:39:26,480

uh um

1025

00:39:33,589 --> 00:39:30,160

the surrounding heat bath can supply

1026

00:39:36,870 --> 00:39:33,599

uh the necessary energy you might say um

1027

00:39:39,589 --> 00:39:36,880

given uh the epic catalysis uh

1028

00:39:42,150 --> 00:39:39,599

the thermal diode idea uh have you

1029

00:39:44,790 --> 00:39:42,160

determined whether there's a minimum

1030

00:39:45,670 --> 00:39:44,800

usable temperature for an ambient heat

1031

00:39:46,790 --> 00:39:45,680

bath

1032

00:39:49,030 --> 00:39:46,800

that would

1033

00:39:50,069 --> 00:39:49,040

enable us to power

1034

00:40:01,750 --> 00:39:50,079

uh

1035

00:40:06,630 --> 00:40:01,760

or

1036

00:40:07,910 --> 00:40:06,640

sure thank you okay um you asked the

1037

00:40:10,390 --> 00:40:07,920

questions which would take a day to

1038

00:40:12,150 --> 00:40:10,400

answer but i'll give you a brief one in

1039

00:40:13,430 --> 00:40:12,160

terms of the arrow of time there are

1040

00:40:15,510 --> 00:40:13,440

multiple arrows of time that have been

1041

00:40:17,670 --> 00:40:15,520

proposed for everyday life the second

1042

00:40:19,670 --> 00:40:17,680

law is considered to be um what's called

1043

00:40:20,790 --> 00:40:19,680

the thermodynamic arrow pushing things

1044

00:40:22,150 --> 00:40:20,800

forward i've written a little bit about

1045

00:40:23,990 --> 00:40:22,160

it i'd be happy to send something along

1046

00:40:25,750 --> 00:40:24,000

if you're interested i think your second

1047

00:40:28,470 --> 00:40:25,760

question um i think is maybe more

1048

00:40:29,910 --> 00:40:28,480

pertinent right now which is

1049

00:40:32,230 --> 00:40:29,920

what kind of how big of a device would

1050

00:40:33,190 --> 00:40:32,240

be needed to actually uh you know power

1051
00:40:34,069 --> 00:40:33,200
a house

1052
00:40:35,349 --> 00:40:34,079
well

1053
00:40:37,030 --> 00:40:35,359
if you have room temperature

1054
00:40:38,790 --> 00:40:37,040
epicatalysis

1055
00:40:40,870 --> 00:40:38,800
the power densities are still real

1056
00:40:42,230 --> 00:40:40,880
really quite large so if you were to

1057
00:40:43,750 --> 00:40:42,240
have something roughly the size of a

1058
00:40:47,270 --> 00:40:43,760
large coffee can

1059
00:40:49,190 --> 00:40:47,280
and um and you pull some air through it

1060
00:40:50,870 --> 00:40:49,200
at a few meters a second

1061
00:40:53,589 --> 00:40:50,880
and as the air goes through it cools

1062
00:40:54,950 --> 00:40:53,599
maybe 10 degrees c so comes in at 20 it

1063
00:40:56,790 --> 00:40:54,960

leaves at 10

1064

00:40:59,750 --> 00:40:56,800

then that would be able to prove produce

1065

00:41:01,589 --> 00:40:59,760

based on on the numbers we have of a

1066

00:41:03,430 --> 00:41:01,599

couple kilowatts easily

1067

00:41:05,349 --> 00:41:03,440

enough to power a house so you could

1068

00:41:07,990 --> 00:41:05,359

basically power a house with maybe a

1069

00:41:09,190 --> 00:41:08,000

panel the size of a large picture on one

1070

00:41:11,030 --> 00:41:09,200

side of your room which would draw heat

1071

00:41:12,309 --> 00:41:11,040

from your environment and power

1072

00:41:14,470 --> 00:41:12,319

everything in your house but of course

1073

00:41:16,230 --> 00:41:14,480

your house is going to be creating uh

1074

00:41:17,670 --> 00:41:16,240

expelling heat from your computer

1075

00:41:20,470 --> 00:41:17,680

refrigerator and everything else which

1076

00:41:24,550 --> 00:41:20,480

just keeps cycle going so you can have a

1077

00:41:27,109 --> 00:41:24,560

closed system with uh with fairly small

1078

00:41:31,510 --> 00:41:27,119

epic catalytic devices

1079

00:41:37,270 --> 00:41:32,390

okay

1080

00:41:41,589 --> 00:41:39,109

my areas in artificial intelligence and

1081

00:41:43,670 --> 00:41:41,599

computer science uh computation

1082

00:41:45,589 --> 00:41:43,680

reasoning about reasoning uh how you

1083

00:41:47,349 --> 00:41:45,599

develop reasoning systems i like really

1084

00:41:49,349 --> 00:41:47,359

love the way that you started your

1085

00:41:51,990 --> 00:41:49,359

presentation when you're talking about

1086

00:41:53,829 --> 00:41:52,000

every law is an axiom and

1087

00:41:55,910 --> 00:41:53,839

from a computational perspective every

1088

00:41:58,470 --> 00:41:55,920

model of science every type of reasoning

1089

00:42:00,790 --> 00:41:58,480

is is nothing more than a true a tool to

1090

00:42:03,510 --> 00:42:00,800

say that some some law is true or

1091

00:42:05,349 --> 00:42:03,520

something or other is is as good as

1092

00:42:06,390 --> 00:42:05,359

saying a wrench is true

1093

00:42:08,550 --> 00:42:06,400

there's lots of different types of

1094

00:42:11,829 --> 00:42:08,560

wrenches used for different purposes

1095

00:42:13,910 --> 00:42:11,839

um so that was great uh there's another

1096

00:42:17,670 --> 00:42:13,920

and i have a presentations online middle

1097

00:42:19,349 --> 00:42:17,680

level science uh youtube um but uh you

1098

00:42:20,390 --> 00:42:19,359

know the next step is you start getting

1099

00:42:22,790 --> 00:42:20,400

a list

1100

00:42:25,270 --> 00:42:22,800

of different types of okay well here's

1101

00:42:27,589 --> 00:42:25,280

an example of entropy in this very sub

1102

00:42:29,430 --> 00:42:27,599

you know one subspace but you can also

1103

00:42:30,790 --> 00:42:29,440

look at structure being created all over

1104

00:42:32,230 --> 00:42:30,800

the place there's lots of different

1105

00:42:33,190 --> 00:42:32,240

places where you see structure being

1106

00:42:34,309 --> 00:42:33,200

created

1107

00:42:36,150 --> 00:42:34,319

um

1108

00:42:37,589 --> 00:42:36,160

whether it's life artificial life

1109

00:42:38,790 --> 00:42:37,599

cosmological

1110

00:42:41,589 --> 00:42:38,800

the structure is being tried you can

1111

00:42:43,030 --> 00:42:41,599

create just a as long list for structure

1112

00:42:46,550 --> 00:42:43,040

being created

1113

00:42:47,829 --> 00:42:46,560

um and you'd be nice to see that type of

1114

00:42:51,750 --> 00:42:47,839

list also

1115

00:42:53,990 --> 00:42:51,760

uh third perpetual um all energy that we

1116

00:42:55,829 --> 00:42:54,000

use in the real world is perpetual

1117

00:42:57,910 --> 00:42:55,839

whether we're taking from the sun we're

1118

00:42:58,790 --> 00:42:57,920

thinking for geothermal

1119

00:43:00,710 --> 00:42:58,800

water

1120

00:43:03,109 --> 00:43:00,720

uh whether you're even actually burning

1121

00:43:05,270 --> 00:43:03,119

fuels that those chemical reactions from

1122

00:43:07,750 --> 00:43:05,280

an energetic formula perspective

1123

00:43:09,349 --> 00:43:07,760

equation perspective each one of them is

1124

00:43:11,670 --> 00:43:09,359

perpetual because you're always getting

1125

00:43:13,510 --> 00:43:11,680

this chain one after the other it's just

1126

00:43:16,470 --> 00:43:13,520

supplying the fuel which is not part of

1127

00:43:18,790 --> 00:43:16,480

the energy equation same with nuclear so

1128

00:43:20,790 --> 00:43:18,800

to say that you know there's no such

1129

00:43:22,790 --> 00:43:20,800

thing as perpetual energy ev all the

1130

00:43:24,950 --> 00:43:22,800

energy we use is perpetual we're taking

1131

00:43:27,030 --> 00:43:24,960

it from the environment

1132

00:43:29,109 --> 00:43:27,040

um fourth and i'm not just going over

1133

00:43:31,750 --> 00:43:29,119

points and i'm trying to to get to

1134

00:43:32,550 --> 00:43:31,760

something to a question

1135

00:43:34,950 --> 00:43:32,560

um

1136

00:43:36,630 --> 00:43:34,960

in some sense you could say that the

1137

00:43:38,790 --> 00:43:36,640

second law since there's been so many

1138

00:43:40,710 --> 00:43:38,800

different iterations of it it can't

1139

00:43:42,790 --> 00:43:40,720

really be a law because these are just

1140

00:43:45,190 --> 00:43:42,800

all just general concepts

1141

00:43:46,150 --> 00:43:45,200

but it's as you mentioned it's a closed

1142

00:43:48,150 --> 00:43:46,160

system

1143

00:43:51,589 --> 00:43:48,160

but what the second law is basically

1144

00:43:54,150 --> 00:43:51,599

saying that at the crux of it is it's

1145

00:43:56,309 --> 00:43:54,160

you can't have one energy system that

1146

00:43:57,349 --> 00:43:56,319

doesn't have some siphoning off into

1147

00:43:59,030 --> 00:43:57,359

another

1148

00:44:00,630 --> 00:43:59,040

so in some sense the second law is

1149

00:44:02,230 --> 00:44:00,640

basically itself

1150

00:44:03,589 --> 00:44:02,240

saying that

1151
00:44:04,790 --> 00:44:03,599
um

1152
00:44:05,670 --> 00:44:04,800
energy

1153
00:44:07,589 --> 00:44:05,680
is

1154
00:44:09,430 --> 00:44:07,599
um

1155
00:44:11,829 --> 00:44:09,440
there's no such thing as a closed energy

1156
00:44:14,150 --> 00:44:11,839
system but the second law itself says

1157
00:44:16,790 --> 00:44:14,160
you were in a closed system because it's

1158
00:44:18,710 --> 00:44:16,800
transforming to another system okay it's

1159
00:44:21,349 --> 00:44:18,720
transferring one thing to another so

1160
00:44:23,349 --> 00:44:21,359
there's a logical inconsistency but

1161
00:44:24,309 --> 00:44:23,359
every computational as a computational

1162
00:44:25,670 --> 00:44:24,319
science

1163
00:44:27,349 --> 00:44:25,680

that's what you have you always have

1164

00:44:28,790 --> 00:44:27,359

singularities paradoxes et cetera and

1165

00:44:31,109 --> 00:44:28,800

computational systems there's you can't

1166

00:44:33,030 --> 00:44:31,119

get away from it the more complex system

1167

00:44:35,030 --> 00:44:33,040

the more involved it is you have those

1168

00:44:36,950 --> 00:44:35,040

things that happen so

1169

00:44:39,190 --> 00:44:36,960

in some sense you you the second law

1170

00:44:40,710 --> 00:44:39,200

says well in a closed system but then

1171

00:44:42,150 --> 00:44:40,720

you really don't can never have a closed

1172

00:44:43,109 --> 00:44:42,160

system because energy transfers into

1173

00:44:44,870 --> 00:44:43,119

another

1174

00:44:47,270 --> 00:44:44,880

so you know i'm sitting here looking at

1175

00:44:49,510 --> 00:44:47,280

computation i started asking why is

1176

00:44:51,030 --> 00:44:49,520

everybody talking about this stuff you

1177

00:44:53,109 --> 00:44:51,040

know well you can't have perpetual but

1178

00:44:55,030 --> 00:44:53,119

it's all perpetual and you know you have

1179

00:44:57,829 --> 00:44:55,040

this law but it's just a tool why why

1180

00:44:59,510 --> 00:44:57,839

are we so focused on these archaic

1181

00:45:02,470 --> 00:44:59,520

concepts that came from a hundred years

1182

00:45:03,750 --> 00:45:02,480

ago okay and and don't relate to

1183

00:45:05,430 --> 00:45:03,760

that computation that's happening in the

1184

00:45:07,030 --> 00:45:05,440

world now yeah

1185

00:45:09,030 --> 00:45:07,040

so justin you've you've touched on all

1186

00:45:10,470 --> 00:45:09,040

the major ideas and non-equilibrium

1187

00:45:11,349 --> 00:45:10,480

thermodynamics and that would take a

1188

00:45:13,109 --> 00:45:11,359

book to

1189

00:45:15,030 --> 00:45:13,119

actually discuss so i'm going to try to

1190

00:45:16,309 --> 00:45:15,040

kind of cut through and just talk kind

1191

00:45:18,230 --> 00:45:16,319

of respond to a couple of your points

1192

00:45:19,109 --> 00:45:18,240

but it'll be okay i can't respond to

1193

00:45:19,910 --> 00:45:19,119

everything

1194

00:45:21,750 --> 00:45:19,920

um

1195

00:45:23,750 --> 00:45:21,760

in in terms of the idea that that all

1196

00:45:25,990 --> 00:45:23,760

energy is perpetual well energy is

1197

00:45:28,710 --> 00:45:26,000

conserved mass energy is conserved in

1198

00:45:30,710 --> 00:45:28,720

reactions at least at our level and um

1199

00:45:32,550 --> 00:45:30,720

so when you say it's perpetual

1200

00:45:35,030 --> 00:45:32,560

fine i mean you can have work being

1201
00:45:36,470 --> 00:45:35,040
degraded down into heat and and now the

1202
00:45:37,750 --> 00:45:36,480
the macroscopic energy becomes

1203
00:45:39,349 --> 00:45:37,760
microscopic

1204
00:45:40,230 --> 00:45:39,359
energy and you say well that's perpetual

1205
00:45:42,390 --> 00:45:40,240
well

1206
00:45:45,349 --> 00:45:42,400
um i i guess the way thermodynamics

1207
00:45:47,670 --> 00:45:45,359
handles it is is that it has to do with

1208
00:45:49,430 --> 00:45:47,680
the quality of the energy

1209
00:45:52,309 --> 00:45:49,440
and once it gets down to the to the

1210
00:45:55,510 --> 00:45:52,319
molecular level it's it can't can't be

1211
00:45:56,710 --> 00:45:55,520
used easily again to for for work so i i

1212
00:45:58,470 --> 00:45:56,720
guess i would take exception with the

1213
00:45:59,750 --> 00:45:58,480

idea that it's perpetual

1214

00:46:01,270 --> 00:45:59,760

although i think you're really pointing

1215

00:46:02,950 --> 00:46:01,280

to the idea of conservation of energy

1216

00:46:06,069 --> 00:46:02,960

which is the first law

1217

00:46:07,910 --> 00:46:06,079

um as for creating structure um yes the

1218

00:46:09,990 --> 00:46:07,920

world creates structure but it creates

1219

00:46:12,710 --> 00:46:10,000

it because of the non-equilibrium nature

1220

00:46:14,309 --> 00:46:12,720

of the world if you drive a system uh

1221

00:46:16,150 --> 00:46:14,319

you can get structure out of it so if

1222

00:46:17,829 --> 00:46:16,160

you drive the earth with an entropy

1223

00:46:19,430 --> 00:46:17,839

gradient from the sun to the earth you

1224

00:46:22,230 --> 00:46:19,440

create the biosphere

1225

00:46:24,950 --> 00:46:22,240

but um so it this does not violate the

1226

00:46:27,430 --> 00:46:24,960

second law to create structure um

1227

00:46:29,190 --> 00:46:27,440

because in the process of the process of

1228

00:46:32,550 --> 00:46:29,200

creating structure you end up creating

1229

00:46:35,829 --> 00:46:32,560

more entropy so the second law is a tax

1230

00:46:37,589 --> 00:46:35,839

it on on any kind of natural phenomenon

1231

00:46:39,750 --> 00:46:37,599

it doesn't destroy or create energy it

1232

00:46:41,589 --> 00:46:39,760

simply says that the quality of that

1233

00:46:43,030 --> 00:46:41,599

energy has to be changed in the process

1234

00:46:45,030 --> 00:46:43,040

that you lose a little bit of its

1235

00:46:47,030 --> 00:46:45,040

usefulness along the way

1236

00:46:48,550 --> 00:46:47,040

so i agree with with the spirit of some

1237

00:46:50,309 --> 00:46:48,560

of the things you say although i think

1238

00:46:52,390 --> 00:46:50,319

from the thermodynamic perspective i

1239

00:46:55,109 --> 00:46:52,400

have to disagree

1240

00:46:58,069 --> 00:46:55,119

can i just one follow up to clarify what

1241

00:46:59,990 --> 00:46:58,079

my point was yes um so when i say

1242

00:47:02,390 --> 00:47:00,000

perpetual it means that all of it energy

1243

00:47:04,710 --> 00:47:02,400

is coming from the environment yes that

1244

00:47:07,510 --> 00:47:04,720

whether it's solar what have you whether

1245

00:47:08,630 --> 00:47:07,520

it's stored in in a chemical or or

1246

00:47:10,630 --> 00:47:08,640

in the environment whatever you're

1247

00:47:13,270 --> 00:47:10,640

taking it out you're always taking some

1248

00:47:15,190 --> 00:47:13,280

energy from the environment so all of

1249

00:47:16,870 --> 00:47:15,200

the energy we have is perpetually being

1250

00:47:19,829 --> 00:47:16,880

taken from the environment yeah i agree

1251
00:47:22,309 --> 00:47:19,839
with you and then second

1252
00:47:24,309 --> 00:47:22,319
when you have that loss of energy it's

1253
00:47:26,549 --> 00:47:24,319
going back into the environment somehow

1254
00:47:28,470 --> 00:47:26,559
you know we have conservation it's it

1255
00:47:30,309 --> 00:47:28,480
it's going to be there so it's coming

1256
00:47:32,069 --> 00:47:30,319
from and the second will say well it's

1257
00:47:34,069 --> 00:47:32,079
going to you know it can't all be used

1258
00:47:35,990 --> 00:47:34,079
in one way some of it's going to go off

1259
00:47:36,950 --> 00:47:36,000
into the environment

1260
00:47:39,190 --> 00:47:36,960
again

1261
00:47:40,150 --> 00:47:39,200
perpetual everything's

1262
00:47:42,069 --> 00:47:40,160
right

1263
00:47:43,270 --> 00:47:42,079

but the perpetual nature i think you're

1264

00:47:45,750 --> 00:47:43,280

referring to has to do with is

1265

00:47:48,150 --> 00:47:45,760

conservation rather than its ability to

1266

00:47:49,589 --> 00:47:48,160

actually carry out more useful work so i

1267

00:47:50,710 --> 00:47:49,599

think that's the difference that's our

1268

00:47:53,270 --> 00:47:50,720

difference in what we're the way we're

1269

00:47:54,870 --> 00:47:53,280

discussing it um we're already at the

1270

00:47:57,670 --> 00:47:54,880

top of the hour

1271

00:48:00,309 --> 00:47:57,680

um robert solomon has a question if you

1272

00:48:02,549 --> 00:48:00,319

can make that question 30 seconds or

1273

00:48:03,829 --> 00:48:02,559

less and then also have a very quick

1274

00:48:04,950 --> 00:48:03,839

answer sure

1275

00:48:06,470 --> 00:48:04,960

please

1276

00:48:07,829 --> 00:48:06,480

okay of course i'll be speaking so fast

1277

00:48:09,829 --> 00:48:07,839

you barely be able understand so you'll

1278

00:48:11,670 --> 00:48:09,839

have to play it back at slow speed okay

1279

00:48:14,230 --> 00:48:11,680

basically matter

1280

00:48:15,990 --> 00:48:14,240

persists forever matter is not

1281

00:48:17,990 --> 00:48:16,000

supposedly created or destroyed except

1282

00:48:20,549 --> 00:48:18,000

for equals mc^2 but let's get back

1283

00:48:23,109 --> 00:48:20,559

to the most basic thing stop calling it

1284

00:48:24,710 --> 00:48:23,119

energy we're talking about photons and

1285

00:48:27,190 --> 00:48:24,720

we're talking about photons we're

1286

00:48:30,150 --> 00:48:27,200

talking about accelerated charge

1287

00:48:31,990 --> 00:48:30,160

and that is what's we're talking about

1288

00:48:33,829 --> 00:48:32,000

and if we can get back to what it really

1289

00:48:36,069 --> 00:48:33,839

is instead of using these words like

1290

00:48:38,230 --> 00:48:36,079

energy and so on and we envision a

1291

00:48:41,109 --> 00:48:38,240

universe filled with photons or

1292

00:48:43,109 --> 00:48:41,119

connections between various charges due

1293

00:48:45,190 --> 00:48:43,119

to their acceleration mediated by what

1294

00:48:49,109 --> 00:48:45,200

we call a photon i think we'd be able to

1295

00:48:53,270 --> 00:48:52,069

that might be an enlightened approach