



1
00:00:01,199 --> 00:00:06,630
thank you york

2
00:00:09,750 --> 00:00:07,829
all right this afternoon i'd like to

3
00:00:11,030 --> 00:00:09,760
discuss on the current state of second

4
00:00:12,390 --> 00:00:11,040
law research

5
00:00:13,830 --> 00:00:12,400
and i'd like to give a brief

6
00:00:15,509 --> 00:00:13,840
introduction starting with the

7
00:00:16,470 --> 00:00:15,519
discussion of energy and then moving on

8
00:00:19,590 --> 00:00:16,480
to

9
00:00:21,189 --> 00:00:19,600
and why

10
00:00:22,710 --> 00:00:21,199
one should consider the possibility that

11
00:00:23,590 --> 00:00:22,720
it may be viable sometime in the near

12
00:00:25,830 --> 00:00:23,600
future

13
00:00:27,189 --> 00:00:25,840

and then finally discuss some of the

14

00:00:31,669 --> 00:00:27,199

breadth and

15

00:00:33,670 --> 00:00:31,679

depth of the of the subject

16

00:00:35,190 --> 00:00:33,680

quite literally energy does make the

17

00:00:38,950 --> 00:00:35,200

world go round

18

00:00:41,990 --> 00:00:38,960

rotationally kinetically chemically

19

00:00:43,750 --> 00:00:42,000

economically geopolitically militarily

20

00:00:45,430 --> 00:00:43,760

almost everything you see in the world

21

00:00:46,950 --> 00:00:45,440

is connected with energy because energy

22

00:00:49,430 --> 00:00:46,960

is the currency of change

23

00:00:51,510 --> 00:00:49,440

without it nothing happens the current

24

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

worldwide use of energy is roughly about

25

00:00:55,350 --> 00:00:53,520

15 terawatts now to put that into

26
00:00:58,950 --> 00:00:55,360
perspective it's equivalent roughly

27
00:01:01,029 --> 00:00:58,960
to the energy every five seconds

28
00:01:02,069 --> 00:01:01,039
the power use is equal to that energy of

29
00:01:05,670 --> 00:01:02,079
roughly a world war

30
00:01:07,350 --> 00:01:05,680
ii nuclear bomb going off and by 2025

31
00:01:10,310 --> 00:01:07,360
roughly about 50 percent more energy

32
00:01:12,710 --> 00:01:10,320
will be required to run civilization

33
00:01:13,910 --> 00:01:12,720
and by a modest and conservative

34
00:01:16,149 --> 00:01:13,920
estimate roughly 20

35
00:01:17,190 --> 00:01:16,159
of the world's economy is devoted to

36
00:01:20,390 --> 00:01:17,200
energy to

37
00:01:21,910 --> 00:01:20,400
discovery extraction transportation use

38
00:01:27,030 --> 00:01:21,920

and in the case of the gulf of

39

00:01:30,390 --> 00:01:27,040

remediation from the extraction process

40

00:01:32,789 --> 00:01:30,400

in terms of energy use in general about

41

00:01:34,469 --> 00:01:32,799

85 percent of it is fossil fuel coal

42

00:01:37,030 --> 00:01:34,479

natural gas and oil

43

00:01:38,390 --> 00:01:37,040

the rest nuclear renewables make up a

44

00:01:40,390 --> 00:01:38,400

smaller fraction

45

00:01:41,910 --> 00:01:40,400

by sector roughly a quarter is used in

46

00:01:43,270 --> 00:01:41,920

residential a quarter in industry

47

00:01:45,590 --> 00:01:43,280

quartering commercial quarter and

48

00:01:47,749 --> 00:01:45,600

transport and in terms of world

49

00:01:49,670 --> 00:01:47,759

consumption as of 2002.

50

00:01:51,749 --> 00:01:49,680

uh north america primarily the united

51
00:01:52,630 --> 00:01:51,759
states makes up roughly about 27 percent

52
00:01:56,469 --> 00:01:52,640
of the world's

53
00:01:57,510 --> 00:01:56,479
energy use the rest is in eastern and

54
00:02:00,149 --> 00:01:57,520
western europe

55
00:02:01,830 --> 00:02:00,159
for the first half most of the world

56
00:02:02,389 --> 00:02:01,840
survives on roughly the other half of

57
00:02:05,670 --> 00:02:02,399
this

58
00:02:08,309 --> 00:02:05,680
but if you'll notice china which makes

59
00:02:09,990 --> 00:02:08,319
china and india which make up roughly a

60
00:02:12,070 --> 00:02:10,000
third of the world's population

61
00:02:14,150 --> 00:02:12,080
by themselves only make up a small

62
00:02:16,869 --> 00:02:14,160
fraction now but as they emerge

63
00:02:18,150 --> 00:02:16,879

into first world economies they will

64

00:02:20,949 --> 00:02:18,160

begin to eat up a greater

65

00:02:22,869 --> 00:02:20,959

share of this and of course there are

66

00:02:24,470 --> 00:02:22,879

finite supplies

67

00:02:27,110 --> 00:02:24,480

current estimates are that oil has

68

00:02:30,869 --> 00:02:27,120

roughly about 40 years left

69

00:02:32,949 --> 00:02:30,879

gas about 70 and coal about 250.

70

00:02:35,430 --> 00:02:32,959

this is the famous hubert curve which

71

00:02:36,949 --> 00:02:35,440

was predicted back in the 1950s

72

00:02:38,790 --> 00:02:36,959

predicting the oil production in the

73

00:02:40,229 --> 00:02:38,800

united states versus year

74

00:02:42,630 --> 00:02:40,239

the prediction was that it would peak

75

00:02:44,309 --> 00:02:42,640

roughly in about 1970 and indeed it did

76

00:02:47,270 --> 00:02:44,319

the united states now imports roughly

77

00:02:50,470 --> 00:02:47,280

about 60 percent of its oil

78

00:02:52,150 --> 00:02:50,480

the uber curve for for coal would follow

79

00:02:54,470 --> 00:02:52,160

something along these lines

80

00:02:56,390 --> 00:02:54,480

um we're here right now coming up coming

81

00:02:57,030 --> 00:02:56,400

up the curve it should peak around 2100

82

00:02:59,670 --> 00:02:57,040

or so

83

00:03:01,670 --> 00:02:59,680

and then um tail off from there but if

84

00:03:03,030 --> 00:03:01,680

we put all this co2 into the atmosphere

85

00:03:04,149 --> 00:03:03,040

i think we all know we'll burn down the

86

00:03:05,270 --> 00:03:04,159

planet

87

00:03:07,270 --> 00:03:05,280

so the inconvenient truth and

88

00:03:08,470 --> 00:03:07,280

consequences of this obviously climate

89

00:03:10,229 --> 00:03:08,480

and environmental change

90

00:03:12,309 --> 00:03:10,239

pollution global warming ecosystem

91

00:03:13,990 --> 00:03:12,319

destruction and many

92

00:03:15,589 --> 00:03:14,000

biologists believe we are in the middle

93

00:03:17,350 --> 00:03:15,599

or the beginning of a mass extinction

94

00:03:19,110 --> 00:03:17,360

which will be comparable to the previous

95

00:03:22,630 --> 00:03:19,120

five in the last half a billion years

96

00:03:25,110 --> 00:03:22,640

the ordovician the devonian the permian

97

00:03:27,589 --> 00:03:25,120

250 million years ago the great dying

98

00:03:30,470 --> 00:03:27,599

the jurassic triassic and the cretaceous

99

00:03:32,470 --> 00:03:30,480

tertiary which was 65 million years ago

100

00:03:33,990 --> 00:03:32,480

this mass extinction that was being

101
00:03:37,110 --> 00:03:34,000
overseen by us

102
00:03:38,070 --> 00:03:37,120
through all of these all of these terms

103
00:03:39,350 --> 00:03:38,080
above

104
00:03:41,270 --> 00:03:39,360
and obviously there are insufficient

105
00:03:43,110 --> 00:03:41,280
supplies of energy there

106
00:03:44,550 --> 00:03:43,120
um we have economic instability as a

107
00:03:46,949 --> 00:03:44,560
result of this fuel and

108
00:03:48,149 --> 00:03:46,959
food shortages social and rest and

109
00:03:49,509 --> 00:03:48,159
judging from some of the recent

110
00:03:51,509 --> 00:03:49,519
activities of

111
00:03:53,990 --> 00:03:51,519
the united states can also lead to

112
00:03:56,710 --> 00:03:54,000
military interventions

113
00:03:57,750 --> 00:03:56,720

the alternatives to fossil fuels and and

114

00:03:59,990 --> 00:03:57,760

nuclear

115

00:04:02,789 --> 00:04:00,000

are numerous have solar thermal

116

00:04:04,149 --> 00:04:02,799

photovoltaic hydro wind tidal geothermal

117

00:04:07,190 --> 00:04:04,159

but all of these have their

118

00:04:10,390 --> 00:04:07,200

disadvantages in terms of capital costs

119

00:04:11,509 --> 00:04:10,400

scale size efficiency renewability unit

120

00:04:13,990 --> 00:04:11,519

cost and so on

121

00:04:14,949 --> 00:04:14,000

such that it's unlikely that any of them

122

00:04:17,590 --> 00:04:14,959

or even all of them

123

00:04:18,789 --> 00:04:17,600

will be able to fill the energy vacuum

124

00:04:22,069 --> 00:04:18,799

that will exist

125

00:04:24,870 --> 00:04:22,079

in the near future so

126

00:04:25,909 --> 00:04:24,880

what would be an ideal energy source if

127

00:04:27,590 --> 00:04:25,919

you were to just

128

00:04:28,790 --> 00:04:27,600

write down a few characteristics

129

00:04:30,070 --> 00:04:28,800

something you might consider to be an

130

00:04:31,670 --> 00:04:30,080

ideal energy source

131

00:04:33,749 --> 00:04:31,680

it should be one that is ubiquitous

132

00:04:34,950 --> 00:04:33,759

found everywhere it should have a high

133

00:04:37,110 --> 00:04:34,960

power density

134

00:04:38,469 --> 00:04:37,120

now you may think solar power is good

135

00:04:39,270 --> 00:04:38,479

but it does not have a high power

136

00:04:41,590 --> 00:04:39,280

density

137

00:04:43,030 --> 00:04:41,600

roughly if you put solar panels out and

138

00:04:43,830 --> 00:04:43,040

collect all the sunlight coming from the

139

00:04:45,830 --> 00:04:43,840

sky

140

00:04:47,189 --> 00:04:45,840

on a square meter of surface area at

141

00:04:49,350 --> 00:04:47,199

normal incidence you'll get roughly a

142

00:04:51,430 --> 00:04:49,360

kilowatt of solar power coming in

143

00:04:53,110 --> 00:04:51,440

of which you might be able to glean 20

144

00:04:54,790 --> 00:04:53,120

of that and you won't get any more than

145

00:04:56,070 --> 00:04:54,800

that so you'll never be able to get more

146

00:04:57,990 --> 00:04:56,080

than about let's say 200

147

00:04:59,189 --> 00:04:58,000

watts per square meter and that's all

148

00:05:02,150 --> 00:04:59,199

you'll be able to get

149

00:05:03,189 --> 00:05:02,160

so to power a city you need acres or

150

00:05:06,230 --> 00:05:03,199

square miles

151
00:05:06,629 --> 00:05:06,240
of such solar panels in order to handle

152
00:05:11,110 --> 00:05:06,639
it

153
00:05:13,510 --> 00:05:11,120
sense the

154
00:05:15,110 --> 00:05:13,520
um the concentration of energy and so

155
00:05:16,469 --> 00:05:15,120
you want a high concentration

156
00:05:18,390 --> 00:05:16,479
of power and energy coming out of your

157
00:05:19,430 --> 00:05:18,400
ideal source it should be green and

158
00:05:21,830 --> 00:05:19,440
non-polluting

159
00:05:23,670 --> 00:05:21,840
plentiful and inexhaustible so what

160
00:05:25,670 --> 00:05:23,680
might this mean

161
00:05:27,670 --> 00:05:25,680
well the most ubiquitous energy source

162
00:05:28,150 --> 00:05:27,680
available i should not say available

163
00:05:30,870 --> 00:05:28,160

around

164

00:05:32,310 --> 00:05:30,880

us is thermal energy the air molecules

165

00:05:33,430 --> 00:05:32,320

in this room the nitrogen and oxygen

166

00:05:36,070 --> 00:05:33,440

molecules are moving

167

00:05:37,510 --> 00:05:36,080

roughly about 400 meters per second

168

00:05:39,029 --> 00:05:37,520

roughly the speed of sound

169

00:05:40,870 --> 00:05:39,039

constantly we don't feel it because

170

00:05:42,469 --> 00:05:40,880

they're small and the average

171

00:05:44,310 --> 00:05:42,479

their average momenta when they bounce

172

00:05:46,629 --> 00:05:44,320

off of us add to zero so we really don't

173

00:05:48,469 --> 00:05:46,639

notice it

174

00:05:49,990 --> 00:05:48,479

um a glass of water for instance the one

175

00:05:51,830 --> 00:05:50,000

that are sitting on your desk right now

176

00:05:53,909 --> 00:05:51,840

a full glass of water in terms of

177

00:05:55,830 --> 00:05:53,919

thermal energy has roughly the

178

00:05:58,230 --> 00:05:55,840

thermal energy equivalent of roughly

179

00:05:59,749 --> 00:05:58,240

about one tenth of a kilogram of tnt

180

00:06:01,670 --> 00:05:59,759

and that includes everything else in

181

00:06:02,469 --> 00:06:01,680

this room the ceiling tiles the rugs on

182

00:06:05,670 --> 00:06:02,479

the floor

183

00:06:07,270 --> 00:06:05,680

the um the tables are flesh everything

184

00:06:08,790 --> 00:06:07,280

is loaded with energy

185

00:06:11,909 --> 00:06:08,800

but it's in a form that can't be used

186

00:06:13,270 --> 00:06:11,919

easily the atmosphere ocean and crust

187

00:06:15,189 --> 00:06:13,280

if you were to add up all the all the

188

00:06:15,990 --> 00:06:15,199

thermal energy in these three in the

189

00:06:17,909 --> 00:06:16,000

upper crust

190

00:06:19,590 --> 00:06:17,919

and the atmosphere and ocean you'd have

191

00:06:21,110 --> 00:06:19,600

roughly 10 000 times

192

00:06:22,950 --> 00:06:21,120

the amount of energy in all the fossil

193

00:06:23,909 --> 00:06:22,960

refuel reserves that are known

194

00:06:26,790 --> 00:06:23,919

and these are constantly being

195

00:06:28,550 --> 00:06:26,800

replenished by solar and radioactivity

196

00:06:32,150 --> 00:06:28,560

in the crust

197

00:06:33,990 --> 00:06:32,160

it is essentially it is plentiful and in

198

00:06:35,270 --> 00:06:34,000

principle and exhaustible if you can get

199

00:06:37,590 --> 00:06:35,280

at it

200

00:06:39,189 --> 00:06:37,600

so thermal energy has all the

201
00:06:40,150 --> 00:06:39,199
characteristics and principle that you

202
00:06:41,270 --> 00:06:40,160
would want out of a

203
00:06:43,189 --> 00:06:41,280
out of an energy source that's

204
00:06:45,670 --> 00:06:43,199
ubiquitous high power density

205
00:06:46,870 --> 00:06:45,680
plentiful inexhaustible recyclable but

206
00:06:47,749 --> 00:06:46,880
not really

207
00:06:49,189 --> 00:06:47,759
because of the second law of

208
00:06:50,390 --> 00:06:49,199
thermodynamics which is probably the

209
00:06:54,070 --> 00:06:50,400
most depressing law

210
00:06:59,749 --> 00:06:57,110
there are four laws of thermodynamics

211
00:07:01,270 --> 00:06:59,759
the first is actually called the zeroth

212
00:07:02,629 --> 00:07:01,280
because it was thought of afterwards and

213
00:07:03,909 --> 00:07:02,639

so since they already named the first

214

00:07:04,790 --> 00:07:03,919

second and third they had to go back and

215

00:07:06,150 --> 00:07:04,800

throw in another one

216

00:07:07,990 --> 00:07:06,160

if another law is found it'd be called a

217

00:07:10,950 --> 00:07:08,000

negative first probably

218

00:07:11,270 --> 00:07:10,960

um but the zeroth and third law which on

219

00:07:14,309 --> 00:07:11,280

the

220

00:07:16,309 --> 00:07:14,319

exist you can measure

221

00:07:17,830 --> 00:07:16,319

equilibrium you can measure temperature

222

00:07:19,830 --> 00:07:17,840

it's basically a definition

223

00:07:21,029 --> 00:07:19,840

and and also the third law is basically

224

00:07:23,830 --> 00:07:21,039

a throw away as well

225

00:07:25,270 --> 00:07:23,840

it talks about fiduciary entropies but

226

00:07:28,070 --> 00:07:25,280

the first and second laws

227

00:07:29,670 --> 00:07:28,080

they are the heart and they are the soul

228

00:07:30,950 --> 00:07:29,680

of thermodynamics they are the flesh and

229

00:07:32,790 --> 00:07:30,960

the blood

230

00:07:34,390 --> 00:07:32,800

this tells you as as mentioned

231

00:07:35,430 --> 00:07:34,400

previously it's a bookkeeping technique

232

00:07:37,430 --> 00:07:35,440

in a sense

233

00:07:39,990 --> 00:07:37,440

but the second law tells you what you

234

00:07:42,550 --> 00:07:40,000

can and cannot do

235

00:07:44,390 --> 00:07:42,560

and we understand this in our bones we

236

00:07:45,189 --> 00:07:44,400

have lots of colloquial statements about

237

00:07:46,869 --> 00:07:45,199

the second law

238

00:07:48,869 --> 00:07:46,879

heat flows from hot to cold not the

239

00:07:52,390 --> 00:07:48,879

other way around messes fill

240

00:07:54,550 --> 00:07:52,400

the space available to to them um

241

00:07:56,070 --> 00:07:54,560

murphy's laws anything can go wrong

242

00:07:57,670 --> 00:07:56,080

wrong at will situations tend to

243

00:07:59,350 --> 00:07:57,680

progress from bad to worse

244

00:08:01,909 --> 00:07:59,360

and of course the one you learned in

245

00:08:04,070 --> 00:08:01,919

kindergarten which is drilled into you

246

00:08:05,749 --> 00:08:04,080

for your whole life perpetual motion

247

00:08:07,350 --> 00:08:05,759

machines are impossible

248

00:08:09,670 --> 00:08:07,360

and this is probably the most damning of

249

00:08:10,469 --> 00:08:09,680

them the technical formulations of the

250

00:08:12,790 --> 00:08:10,479

second law

251
00:08:14,390 --> 00:08:12,800
are also numerous the one that i prefer

252
00:08:15,830 --> 00:08:14,400
is the kelvin punk one which goes back

253
00:08:17,430 --> 00:08:15,840
150 years

254
00:08:18,629 --> 00:08:17,440
no device operating in a cycle can

255
00:08:19,510 --> 00:08:18,639
produce the sole effect of the

256
00:08:21,909 --> 00:08:19,520
extraction

257
00:08:23,270 --> 00:08:21,919
of a quantity of heat from a reservoir

258
00:08:24,710 --> 00:08:23,280
and the performance of an equal quantity

259
00:08:27,189 --> 00:08:24,720
of work which basically says

260
00:08:28,950 --> 00:08:27,199
you can't take heat and turn it solely

261
00:08:30,950 --> 00:08:28,960
into work with nothing else happening

262
00:08:32,070 --> 00:08:30,960
you can't take that disorganized

263
00:08:36,469 --> 00:08:32,080

molecular motion

264

00:08:40,790 --> 00:08:39,350

um klausur's heat basically is one that

265

00:08:41,670 --> 00:08:40,800

says heat goes from hot to cold not the

266

00:08:44,149 --> 00:08:41,680

other way around

267

00:08:45,670 --> 00:08:44,159

perpetual motion machines are impossible

268

00:08:47,430 --> 00:08:45,680

perfect refrigerators are impossible

269

00:08:50,470 --> 00:08:47,440

perfect heating is not

270

00:08:51,430 --> 00:08:50,480

are impossible um all natural processes

271

00:08:52,949 --> 00:08:51,440

are irreversible

272

00:08:55,110 --> 00:08:52,959

the entropy of the universe constantly

273

00:08:57,509 --> 00:08:55,120

increases or at least never decreases

274

00:08:59,190 --> 00:08:57,519

we're all going to die okay so this the

275

00:09:00,790 --> 00:08:59,200

second law basically says that

276

00:09:03,190 --> 00:09:00,800

the universe tends toward greater

277

00:09:05,350 --> 00:09:03,200

disorder energy runs down

278

00:09:06,230 --> 00:09:05,360

the second law takes a tax on every

279

00:09:08,230 --> 00:09:06,240

single

280

00:09:09,670 --> 00:09:08,240

thermodynamic process in the universe it

281

00:09:11,190 --> 00:09:09,680

takes away some of that energy which you

282

00:09:13,350 --> 00:09:11,200

can never recover

283

00:09:15,190 --> 00:09:13,360

um in the book valada kopik and i wrote

284

00:09:16,790 --> 00:09:15,200

several years ago we actually found 21

285

00:09:17,910 --> 00:09:16,800

different formulations of the second law

286

00:09:19,190 --> 00:09:17,920

of thermodynamics

287

00:09:21,190 --> 00:09:19,200

some of which don't even seem to agree

288

00:09:22,389 --> 00:09:21,200

with each other but there are many

289

00:09:24,470 --> 00:09:22,399

different forms of it

290

00:09:26,389 --> 00:09:24,480

and as clifford truesdale once noted the

291

00:09:28,389 --> 00:09:26,399

famous historian of science

292

00:09:29,430 --> 00:09:28,399

every physicist knows exactly what the

293

00:09:31,269 --> 00:09:29,440

first and second law

294

00:09:34,829 --> 00:09:31,279

of thermodynamics are the only problem

295

00:09:36,310 --> 00:09:34,839

is no two physicists agree on what they

296

00:09:39,430 --> 00:09:36,320

are

297

00:09:40,630 --> 00:09:39,440

there is what i would call the second

298

00:09:44,230 --> 00:09:40,640

law of mystique

299

00:09:45,350 --> 00:09:44,240

there is a cocoon an intellectual cocoon

300

00:09:46,790 --> 00:09:45,360

around the second law

301

00:09:48,470 --> 00:09:46,800

that makes it almost impossible to

302

00:09:50,310 --> 00:09:48,480

discuss in a rational way

303

00:09:52,470 --> 00:09:50,320

in the scientific community and the most

304

00:09:54,070 --> 00:09:52,480

famous quote about it is by arthur

305

00:09:54,710 --> 00:09:54,080

eddington who happens to happen to have

306

00:09:56,710 --> 00:09:54,720

been

307

00:09:57,910 --> 00:09:56,720

a scientist of equal caliber and stature

308

00:10:00,150 --> 00:09:57,920

to albert einstein

309

00:10:01,269 --> 00:10:00,160

in the early 20th century and for those

310

00:10:03,190 --> 00:10:01,279

of you in the back

311

00:10:04,949 --> 00:10:03,200

the law that entropy increases the

312

00:10:06,710 --> 00:10:04,959

second law of thermodynamics

313

00:10:08,310 --> 00:10:06,720

holds i think the supreme position among

314

00:10:10,389 --> 00:10:08,320

the laws of nature

315

00:10:11,590 --> 00:10:10,399

if someone points out to you that your

316

00:10:13,350 --> 00:10:11,600

pet theory of the universe is in

317

00:10:14,949 --> 00:10:13,360

disagreement with maxwell's equations

318

00:10:15,910 --> 00:10:14,959

well so much the worst for maxwell's

319

00:10:17,509 --> 00:10:15,920

equations

320

00:10:18,949 --> 00:10:17,519

if it is found to be contradicted by

321

00:10:20,710 --> 00:10:18,959

observation well

322

00:10:22,069 --> 00:10:20,720

these experimentalists bungle things

323

00:10:23,190 --> 00:10:22,079

sometimes

324

00:10:24,550 --> 00:10:23,200

but if your theory is found to be

325

00:10:26,630 --> 00:10:24,560

against the second law of thermodynamics

326

00:10:28,310 --> 00:10:26,640

i can give you no hope

327

00:10:32,470 --> 00:10:28,320

there is nothing for it but to collapse

328

00:10:34,150 --> 00:10:32,480

and deepest humiliation

329

00:10:36,230 --> 00:10:34,160

and this is the general uh tenor of

330

00:10:39,590 --> 00:10:36,240

remarks regarding the second law

331

00:10:41,110 --> 00:10:39,600

it is an unquestioned axiom

332

00:10:43,430 --> 00:10:41,120

but one of the things that is often

333

00:10:46,630 --> 00:10:43,440

forgotten is that the laws of nature

334

00:10:49,750 --> 00:10:46,640

are not set in stone they are discovered

335

00:10:52,870 --> 00:10:49,760

and on purely epistemological grounds

336

00:10:54,870 --> 00:10:52,880

they cannot ever be fully proven

337

00:10:56,630 --> 00:10:54,880

they can only be verified and you can go

338

00:10:58,710 --> 00:10:56,640

no farther if you wish them to

339

00:11:00,470 --> 00:10:58,720

david hume's problem of induction to

340

00:11:02,150 --> 00:11:00,480

show that to be the case

341

00:11:03,670 --> 00:11:02,160

laws of nature are true because they are

342

00:11:05,750 --> 00:11:03,680

found to be true

343

00:11:08,710 --> 00:11:05,760

if you could prove them they would be

344

00:11:11,190 --> 00:11:08,720

theorems of deeper axioms

345

00:11:12,389 --> 00:11:11,200

so and furthermore laws must be updated

346

00:11:14,710 --> 00:11:12,399

on a regular basis

347

00:11:16,230 --> 00:11:14,720

and made more precise so let's take an

348

00:11:19,190 --> 00:11:16,240

example

349

00:11:20,310 --> 00:11:19,200

the laws of gravity back about 300 bc

350

00:11:23,190 --> 00:11:20,320

aristotle said

351

00:11:24,870 --> 00:11:23,200

things fall that's gravity why because

352

00:11:26,230 --> 00:11:24,880

they fall to where they like to be which

353

00:11:28,069 --> 00:11:26,240

is the ground

354

00:11:30,870 --> 00:11:28,079

and to show how persuasive that argument

355

00:11:33,430 --> 00:11:30,880

is it held 1500 years

356

00:11:34,790 --> 00:11:33,440

so he's a very smart guy newton came

357

00:11:36,550 --> 00:11:34,800

along and developed his

358

00:11:38,150 --> 00:11:36,560

basic theory of gravity universal theory

359

00:11:40,230 --> 00:11:38,160

of gravity which was updated a couple

360

00:11:42,069 --> 00:11:40,240

hundred years later by einstein

361

00:11:44,150 --> 00:11:42,079

but even within 20 30 years after

362

00:11:45,750 --> 00:11:44,160

einstein discovered his theory of

363

00:11:47,670 --> 00:11:45,760

of gravity the general theory of

364

00:11:48,230 --> 00:11:47,680

relativity it was already known that it

365

00:11:49,509 --> 00:11:48,240

was wrong

366

00:11:51,509 --> 00:11:49,519

because it didn't incorporate quantum

367

00:11:53,269 --> 00:11:51,519

mechanics and even to this day

368

00:11:55,670 --> 00:11:53,279

better part of a century later we do not

369

00:11:57,110 --> 00:11:55,680

have a viable theory of quantum gravity

370

00:11:59,590 --> 00:11:57,120

so even if something as simple as

371

00:12:03,269 --> 00:11:59,600

gravity constantly needs to be

372

00:12:05,509 --> 00:12:03,279

revised and updated on a regular basis

373

00:12:07,350 --> 00:12:05,519

conservation of energy is another one

374

00:12:08,629 --> 00:12:07,360

until about 1800 there were only two

375

00:12:10,790 --> 00:12:08,639

kinds of energy which were known

376

00:12:13,030 --> 00:12:10,800

connecticut potential energy of motion

377

00:12:14,949 --> 00:12:13,040

the energy of energy and the arrangement

378

00:12:18,150 --> 00:12:14,959

of material for instance

379

00:12:19,430 --> 00:12:18,160

gravitational potential energy by 1850

380

00:12:21,190 --> 00:12:19,440

it was discovered that heat

381

00:12:23,190 --> 00:12:21,200

random molecular motion was another kind

382

00:12:26,069 --> 00:12:23,200

of energy by 1905

383

00:12:27,670 --> 00:12:26,079

rest mass energy was discovered 1940

384

00:12:30,790 --> 00:12:27,680

zero-point energy was

385

00:12:32,710 --> 00:12:30,800

was um recognized well 1970s

386

00:12:33,910 --> 00:12:32,720

false vacuum energy from perhaps which

387

00:12:36,710 --> 00:12:33,920

the universe came from

388

00:12:39,269 --> 00:12:36,720

was discovered 1998 dark energy whenever

389

00:12:40,710 --> 00:12:39,279

a new form of a means by which to change

390

00:12:42,710 --> 00:12:40,720

the universe is discovered

391

00:12:43,990 --> 00:12:42,720

they simply invent with a new kind of

392

00:12:46,470 --> 00:12:44,000

energy is created

393

00:12:49,430 --> 00:12:46,480

and the first law of thermodynamics is

394

00:12:53,509 --> 00:12:51,750

now the history of the second law can

395

00:12:54,069 --> 00:12:53,519

really be traced back almost 200 years

396

00:12:57,269 --> 00:12:54,079

now

397

00:12:58,550 --> 00:12:57,279

to saudi carnot in the in heat engine

398

00:13:01,670 --> 00:12:58,560

efficiencies

399

00:13:03,350 --> 00:13:01,680

but by roughly 1910 no further

400

00:13:04,870 --> 00:13:03,360

statements of the second law

401

00:13:07,110 --> 00:13:04,880

really were being developed it was

402

00:13:09,829 --> 00:13:07,120

considered pretty much set in stone

403

00:13:12,470 --> 00:13:09,839

almost a full century ago since that

404

00:13:15,110 --> 00:13:12,480

time we've had special relativity

405

00:13:16,550 --> 00:13:15,120

we've had quantum mechanics chaos theory

406

00:13:19,269 --> 00:13:16,560

updates in cosmology

407

00:13:20,069 --> 00:13:19,279

virtually any basic law or or statement

408

00:13:21,430 --> 00:13:20,079

in physics

409

00:13:23,829 --> 00:13:21,440

had to have been updated in the last

410

00:13:25,910 --> 00:13:23,839

century but not the second law

411

00:13:28,949 --> 00:13:25,920

my form of the second law goes back 150

412

00:13:34,629 --> 00:13:32,470

so in general laws become rules of thumb

413

00:13:35,750 --> 00:13:34,639

things like the ideal gas law are are

414

00:13:38,310 --> 00:13:35,760

known not to be true

415

00:13:39,910 --> 00:13:38,320

there are no perfect ideal gases but

416

00:13:41,829 --> 00:13:39,920

it's close enough that we can use it we

417

00:13:42,230 --> 00:13:41,839

have charles's law galas sacks raoult's

418

00:13:45,750 --> 00:13:42,240

law

419

00:13:47,750 --> 00:13:45,760

considered approximations

420

00:13:48,790 --> 00:13:47,760

is it possible that the second law

421

00:13:51,910 --> 00:13:48,800

itself which was last

422

00:13:53,110 --> 00:13:51,920

updated 100 years ago roughly is also an

423

00:13:54,870 --> 00:13:53,120

approximation

424

00:13:56,790 --> 00:13:54,880

good for almost everything we deal with

425

00:14:00,550 --> 00:13:56,800

and good for everything we do deal with

426

00:14:01,829 --> 00:14:00,560

but that there might be some crimps some

427

00:14:03,990 --> 00:14:01,839

imperfections in it that might be

428

00:14:06,230 --> 00:14:04,000

exploited because if you can

429

00:14:07,750 --> 00:14:06,240

you can ex in principle you can extract

430

00:14:09,590 --> 00:14:07,760

heat from the environment the amount of

431

00:14:11,750 --> 00:14:09,600

energy in this in the room itself here

432

00:14:12,870 --> 00:14:11,760

is equal to several boxes of tnt enough

433

00:14:14,710 --> 00:14:12,880

energy to run this room

434

00:14:15,990 --> 00:14:14,720

forever since you can in principle then

435

00:14:19,110 --> 00:14:16,000

recycle that energy

436

00:14:23,750 --> 00:14:19,120

into lights computers projectors food

437

00:14:24,949 --> 00:14:23,760

chemical energy so if the 21st century

438

00:14:26,710 --> 00:14:24,959

actually is essentially when the second

439

00:14:28,389 --> 00:14:26,720

law is broken then the second law will

440

00:14:29,910 --> 00:14:28,399

just have to have a small update for any

441

00:14:31,590 --> 00:14:29,920

spontaneous process the entropy of the

442

00:14:34,949 --> 00:14:31,600

universe never decreases

443

00:14:38,230 --> 00:14:36,870

so challenges to the second law the

444

00:14:39,509 --> 00:14:38,240

first challenge to the second law was a

445

00:14:40,470 --> 00:14:39,519

thought experiment by james clerk

446

00:14:41,829 --> 00:14:40,480

maxwell himself

447

00:14:45,590 --> 00:14:41,839

one of the founders of statistical

448

00:14:48,629 --> 00:14:45,600

mechanics back in 1867 140 years ago

449

00:14:51,189 --> 00:14:48,639

and um and this demon

450

00:14:51,750 --> 00:14:51,199

consists of a of a quick fingered

451
00:14:53,750 --> 00:14:51,760
creature

452
00:14:55,829 --> 00:14:53,760
who can operate a trapdoor and all he

453
00:14:57,350 --> 00:14:55,839
does is operate this trapdoor letting

454
00:14:58,629 --> 00:14:57,360
molecules through when he wants

455
00:15:00,470 --> 00:14:58,639
and keeping out other ones when he

456
00:15:01,509 --> 00:15:00,480
doesn't want them and so you can imagine

457
00:15:03,509 --> 00:15:01,519
that this demon

458
00:15:04,710 --> 00:15:03,519
could selectively let molecules from

459
00:15:07,269 --> 00:15:04,720
this side of the room

460
00:15:08,790 --> 00:15:07,279
this side of the partition come through

461
00:15:10,389 --> 00:15:08,800
while blocking any molecules trying to

462
00:15:12,150 --> 00:15:10,399
come the other way

463
00:15:13,829 --> 00:15:12,160

if he does so then he creates a pressure

464

00:15:15,670 --> 00:15:13,839

differential a large pressure here

465

00:15:17,670 --> 00:15:15,680

and a vacuum over here in which case

466

00:15:19,750 --> 00:15:17,680

this piston can be pushed

467

00:15:21,670 --> 00:15:19,760

and do pressure volume work when he's

468

00:15:23,590 --> 00:15:21,680

done with that he opens up

469

00:15:24,790 --> 00:15:23,600

the store again let's all molecules go

470

00:15:25,750 --> 00:15:24,800

to the other side creates another

471

00:15:27,670 --> 00:15:25,760

pressure differential

472

00:15:29,110 --> 00:15:27,680

pushes them all pushes the piston back

473

00:15:31,350 --> 00:15:29,120

and in principle this creature

474

00:15:32,550 --> 00:15:31,360

could violate the second law it took

475

00:15:34,069 --> 00:15:32,560

better part well

476
00:15:35,590 --> 00:15:34,079
well over 100 years to figure out what's

477
00:15:36,069 --> 00:15:35,600
wrong with this and the problem with it

478
00:15:39,829 --> 00:15:36,079
is

479
00:15:40,710 --> 00:15:39,839
and has to remember and has to erase

480
00:15:42,150 --> 00:15:40,720
information

481
00:15:43,829 --> 00:15:42,160
and in the process of erasing

482
00:15:45,590 --> 00:15:43,839
information from his register

483
00:15:47,590 --> 00:15:45,600
in order to keep this process going in a

484
00:15:51,509 --> 00:15:47,600
cyclic way he

485
00:15:55,430 --> 00:15:53,910
since that time since james clerk

486
00:15:57,990 --> 00:15:55,440
maxwell there was a hiatus

487
00:15:59,590 --> 00:15:58,000
for over a hundred years before any any

488
00:16:01,350 --> 00:15:59,600

challenges to the second law

489

00:16:03,670 --> 00:16:01,360

made it into the scientific literature

490

00:16:05,990 --> 00:16:03,680

there was so complete and embargo on it

491

00:16:07,110 --> 00:16:06,000

this embargo was broken in about 1980 by

492

00:16:10,230 --> 00:16:07,120

two pioneers

493

00:16:10,870 --> 00:16:10,240

jack denier an american and lindsey

494

00:16:13,829 --> 00:16:10,880

gordon

495

00:16:15,430 --> 00:16:13,839

an uh new zealander they snuck a couple

496

00:16:17,509 --> 00:16:15,440

of articles into

497

00:16:19,430 --> 00:16:17,519

very good referee journals which first

498

00:16:21,110 --> 00:16:19,440

raised the hint that there might be a

499

00:16:23,910 --> 00:16:21,120

problem with the second law

500

00:16:24,790 --> 00:16:23,920

roughly about 1980. by 1990 a number of

501
00:16:27,030 --> 00:16:24,800
scientists had caught

502
00:16:28,790 --> 00:16:27,040
caught wind of this and there was really

503
00:16:31,030 --> 00:16:28,800
quite a revolution going on

504
00:16:32,949 --> 00:16:31,040
um here's a list of the modern

505
00:16:35,749 --> 00:16:32,959
challenges to the second law

506
00:16:36,629 --> 00:16:35,759
since 1980 by the research group the

507
00:16:38,949 --> 00:16:36,639
institution

508
00:16:39,910 --> 00:16:38,959
the country the number of researchers in

509
00:16:41,910 --> 00:16:39,920
the research group

510
00:16:44,790 --> 00:16:41,920
and the number of referee publications

511
00:16:46,949 --> 00:16:44,800
in um in physics chemistry journals

512
00:16:47,990 --> 00:16:46,959
that came out of these groups on the far

513
00:16:49,430 --> 00:16:48,000

right is

514

00:16:52,310 --> 00:16:49,440

a demarker as to whether these are

515

00:16:54,550 --> 00:16:52,320

experimentally measurable or not

516

00:16:55,590 --> 00:16:54,560

many of them particularly the group in

517

00:16:58,710 --> 00:16:55,600

in the czech republic

518

00:17:03,509 --> 00:16:58,720

were mostly were all theoretical as were

519

00:17:05,829 --> 00:17:03,519

the ones by denier but one's by nikolov

520

00:17:06,870 --> 00:17:05,839

and keefe and the ones at the university

521

00:17:09,750 --> 00:17:06,880

of san diego

522

00:17:12,309 --> 00:17:09,760

where i work are experimentally testable

523

00:17:14,150 --> 00:17:12,319

and i'd like to focus on those

524

00:17:15,990 --> 00:17:14,160

oh by the way the number of challenges

525

00:17:17,750 --> 00:17:16,000

that have been brought into the refereed

526

00:17:20,549 --> 00:17:17,760

scientific literature in the last

527

00:17:22,230 --> 00:17:20,559

30 years has been over two dozen in over

528

00:17:24,630 --> 00:17:22,240

60 articles

529

00:17:25,270 --> 00:17:24,640

just in the last 15 years most of those

530

00:17:30,710 --> 00:17:25,280

appeared

531

00:17:34,230 --> 00:17:32,470

the experimentally testable challenges

532

00:17:37,350 --> 00:17:34,240

uh the ones that um

533

00:17:38,870 --> 00:17:37,360

are most provocative um two of them work

534

00:17:40,470 --> 00:17:38,880

in the low temperature regime for with

535

00:17:43,909 --> 00:17:40,480

superconductors

536

00:17:46,710 --> 00:17:43,919

um neither has real commercial viability

537

00:17:48,150 --> 00:17:46,720

um the ones that um have been explored

538

00:17:49,750 --> 00:17:48,160

at the university of san diego

539

00:17:51,510 --> 00:17:49,760

um four out of five of those were in

540

00:17:52,470 --> 00:17:51,520

high temperature regimes or regimes

541

00:17:54,390 --> 00:17:52,480

which would not be commercially

542

00:17:56,150 --> 00:17:54,400

available available

543

00:17:57,590 --> 00:17:56,160

but there is a semiconductor one that

544

00:17:58,390 --> 00:17:57,600

that may be in and which is being

545

00:18:00,230 --> 00:17:58,400

pursued

546

00:18:01,990 --> 00:18:00,240

and the work is being supported by um

547

00:18:05,190 --> 00:18:02,000

partially by hub lab

548

00:18:08,710 --> 00:18:05,200

ed beardsworth you have your hand

549

00:18:09,830 --> 00:18:08,720

thank you ed um here's a list of the

550

00:18:11,270 --> 00:18:09,840

journals in which

551
00:18:13,750 --> 00:18:11,280
second law challenges have appeared in

552
00:18:16,150 --> 00:18:13,760
the last 20 years

553
00:18:17,510 --> 00:18:16,160
you'll notice many of these recognize

554
00:18:20,470 --> 00:18:17,520
many of the physical review physical

555
00:18:22,310 --> 00:18:20,480
review letters american journal physics

556
00:18:23,669 --> 00:18:22,320
chemical physics many of the top

557
00:18:26,950 --> 00:18:23,679
journals in in

558
00:18:28,710 --> 00:18:26,960
science have sponsored

559
00:18:29,990 --> 00:18:28,720
and accepted articles having to do with

560
00:18:31,270 --> 00:18:30,000
challenges to the second law

561
00:18:33,190 --> 00:18:31,280
so it can no longer be said that the

562
00:18:35,029 --> 00:18:33,200
second law is immune from discussion

563
00:18:37,350 --> 00:18:35,039

um it has not been violated though by

564

00:18:40,830 --> 00:18:37,360

any experiment and i myself will say

565

00:18:43,510 --> 00:18:40,840

the second law is inviolable until it

566

00:18:46,710 --> 00:18:43,520

isn't

567

00:18:47,990 --> 00:18:46,720

um alexei nikolov in in russia has been

568

00:18:49,830 --> 00:18:48,000

pursuing um

569

00:18:51,510 --> 00:18:49,840

in homogeneous superconducting loops

570

00:18:51,990 --> 00:18:51,520

these are mesoscopic in size roughly

571

00:18:53,909 --> 00:18:52,000

about

572

00:18:55,590 --> 00:18:53,919

a few microns in size they are

573

00:18:58,390 --> 00:18:55,600

superconducting loops of

574

00:18:58,789 --> 00:18:58,400

of aluminum and what he does with them

575

00:19:00,950 --> 00:18:58,799

is

576

00:19:02,150 --> 00:19:00,960

tries to rectify thermal fluctuations

577

00:19:03,590 --> 00:19:02,160

using what's called a little parts

578

00:19:05,029 --> 00:19:03,600

effect near the transition temperature

579

00:19:08,150 --> 00:19:05,039

for superconductivity

580

00:19:09,830 --> 00:19:08,160

he's gotten some anomalous behavior

581

00:19:11,590 --> 00:19:09,840

he has not been able to directly show

582

00:19:12,870 --> 00:19:11,600

he's been converted into work

583

00:19:14,150 --> 00:19:12,880

this work has probably has been

584

00:19:16,710 --> 00:19:14,160

suspended to my knowledge over the last

585

00:19:21,590 --> 00:19:16,720

five years due to lack of funding

586

00:19:23,590 --> 00:19:21,600

in russia peter keith an american

587

00:19:25,830 --> 00:19:23,600

has worked in this area as well i'm also

588

00:19:27,909 --> 00:19:25,840

making mesoscopic

589

00:19:29,909 --> 00:19:27,919

superconductors this would be a normal a

590

00:19:32,710 --> 00:19:29,919

normal conductor this would be a magnet

591

00:19:33,190 --> 00:19:32,720

and these would be magnetic field lines

592

00:19:34,470 --> 00:19:33,200

if the

593

00:19:36,789 --> 00:19:34,480

normal conductor is brought into the

594

00:19:39,190 --> 00:19:36,799

region of the magnetic field and then

595

00:19:40,310 --> 00:19:39,200

undergo the superconducting transition

596

00:19:41,990 --> 00:19:40,320

the meissner effect

597

00:19:43,350 --> 00:19:42,000

will expel the magnetic field lines out

598

00:19:45,270 --> 00:19:43,360

of the out of the conductor

599

00:19:46,630 --> 00:19:45,280

causing the conductor to be expelled and

600

00:19:48,150 --> 00:19:46,640

during this you can do work

601
00:19:50,549 --> 00:19:48,160
and so he proposes what's called a

602
00:19:53,110 --> 00:19:50,559
magneto coherent magneto-caloric

603
00:19:53,750 --> 00:19:53,120
engine in which he works out a work

604
00:19:56,950 --> 00:19:53,760
cycle

605
00:20:00,070 --> 00:19:56,960
i'm using microscopic superconductors to

606
00:20:02,630 --> 00:20:00,080
carry out work banking on the normal to

607
00:20:03,909 --> 00:20:02,640
superconducting transition

608
00:20:05,750 --> 00:20:03,919
the challenges of the university of san

609
00:20:09,350 --> 00:20:05,760
diego go back 20 years now

610
00:20:11,110 --> 00:20:09,360
first ideas were about 1990 late 1990

611
00:20:12,870 --> 00:20:11,120
and they have always focused on ones

612
00:20:13,669 --> 00:20:12,880
which are experimentally testable at

613
00:20:15,270 --> 00:20:13,679

least facets

614

00:20:17,190 --> 00:20:15,280

i should say the underlying physics can

615

00:20:18,310 --> 00:20:17,200

be directly tested so here's a

616

00:20:19,909 --> 00:20:18,320

compendium of them

617

00:20:21,350 --> 00:20:19,919

wherever you see a star indicates

618

00:20:22,070 --> 00:20:21,360

experiments have been done which

619

00:20:23,830 --> 00:20:22,080

corroborate

620

00:20:25,190 --> 00:20:23,840

the fundamental processes underlying the

621

00:20:27,029 --> 00:20:25,200

challenge

622

00:20:29,750 --> 00:20:27,039

i was trained as a plasma physicist so

623

00:20:32,230 --> 00:20:29,760

the first couple were in plasma physics

624

00:20:33,750 --> 00:20:32,240

my undergraduates in chemistry chemist

625

00:20:37,350 --> 00:20:33,760

chemical one was actually the first one

626

00:20:38,390 --> 00:20:37,360

i worked on and then from there these

627

00:20:40,390 --> 00:20:38,400

developed into

628

00:20:42,549 --> 00:20:40,400

various kinds of catalysts and solid

629

00:20:44,549 --> 00:20:42,559

state devices

630

00:20:45,909 --> 00:20:44,559

many of the effects which are discussed

631

00:20:47,510 --> 00:20:45,919

in these particular challenges have been

632

00:20:50,549 --> 00:20:47,520

corroborated by other researchers in

633

00:20:53,190 --> 00:20:50,559

their own independent research

634

00:20:54,070 --> 00:20:53,200

one of whom is sam miller at sandia

635

00:20:55,110 --> 00:20:54,080

national labs

636

00:20:56,789 --> 00:20:55,120

corroborates some of the chemical

637

00:20:58,149 --> 00:20:56,799

research we've done lindsey gordon

638

00:21:00,070 --> 00:20:58,159

corroborates some of the stuff i've

639

00:21:01,510 --> 00:21:00,080

proposed in terms of biology and jack

640

00:21:04,789 --> 00:21:01,520

denier

641

00:21:06,789 --> 00:21:04,799

in terms of the gas laws so

642

00:21:08,549 --> 00:21:06,799

from from the university of san diego

643

00:21:10,870 --> 00:21:08,559

these are the summary of the challenges

644

00:21:12,549 --> 00:21:10,880

on plasma 1 plasma 2 gravitational

645

00:21:14,310 --> 00:21:12,559

chemical solid state

646

00:21:15,830 --> 00:21:14,320

temperature range in which they operate

647

00:21:17,669 --> 00:21:15,840

the plasma ones operate at high

648

00:21:19,909 --> 00:21:17,679

temperature where plasmas exist um

649

00:21:21,190 --> 00:21:19,919

typically about 1500 kelvins so this is

650

00:21:22,870 --> 00:21:21,200

an inhospitable regime

651
00:21:25,190 --> 00:21:22,880
you have to work with exotic metals like

652
00:21:27,270 --> 00:21:25,200
tungsten and tantalum

653
00:21:29,510 --> 00:21:27,280
and molybdenum pressures have to be low

654
00:21:32,070 --> 00:21:29,520
power densities are minute commercial

655
00:21:33,350 --> 00:21:32,080
interest is virtually none the

656
00:21:36,470 --> 00:21:33,360
experiments which were done

657
00:21:39,110 --> 00:21:36,480
on these corroborated the process and

658
00:21:40,310 --> 00:21:39,120
in principle had have had these plasmas

659
00:21:41,270 --> 00:21:40,320
been actually created at room

660
00:21:44,070 --> 00:21:41,280
temperature rather than

661
00:21:45,270 --> 00:21:44,080
1500 kelvin then in principle these

662
00:21:47,029 --> 00:21:45,280
could have been claimed to have been

663
00:21:49,190 --> 00:21:47,039

true second law violators but because of

664

00:21:51,029 --> 00:21:49,200

the high temperature having to run gas

665

00:21:52,549 --> 00:21:51,039

vacuum pumps heating everything up the

666

00:21:53,990 --> 00:21:52,559

amount of entropy i created was

667

00:21:57,190 --> 00:21:54,000

a quadrillion times more than i could

668

00:22:00,789 --> 00:21:57,200

have harvested from these processes

669

00:22:03,270 --> 00:22:00,799

uh chemical processes um uh also um have

670

00:22:04,630 --> 00:22:03,280

high relatively high power densities but

671

00:22:06,710 --> 00:22:04,640

um generally um

672

00:22:08,070 --> 00:22:06,720

uh would not be commercially interesting

673

00:22:08,789 --> 00:22:08,080

i'd like to focus on the solid state

674

00:22:10,390 --> 00:22:08,799

challenges

675

00:22:12,149 --> 00:22:10,400

which have enormous power densities in

676

00:22:13,830 --> 00:22:12,159

principle greater than um in principle

677

00:22:15,669 --> 00:22:13,840

100 megawatts per cubic meter for these

678

00:22:18,950 --> 00:22:15,679

small devices they're microscopic

679

00:22:20,390 --> 00:22:18,960

or to begin with

680

00:22:22,070 --> 00:22:20,400

and they could have commercial interest

681

00:22:24,630 --> 00:22:22,080

these can operate anywhere from

682

00:22:27,830 --> 00:22:24,640

um the boiling point of liquid nitrogen

683

00:22:30,549 --> 00:22:27,840

up to about a thousand kelvin

684

00:22:32,390 --> 00:22:30,559

um the plasma experiments were basically

685

00:22:33,430 --> 00:22:32,400

heating up a cavity to a couple thousand

686

00:22:36,549 --> 00:22:33,440

degrees putting in

687

00:22:37,270 --> 00:22:36,559

disparate metals and putting in an

688

00:22:39,350 --> 00:22:37,280

ionizable

689

00:22:40,950 --> 00:22:39,360

metal like that could be surface ionized

690

00:22:42,390 --> 00:22:40,960

like potassium and seeing whether

691

00:22:43,909 --> 00:22:42,400

the amount of current or the amount of

692

00:22:45,830 --> 00:22:43,919

ionization caused by these different

693

00:22:47,909 --> 00:22:45,840

materials was different if it's if so

694

00:22:49,750 --> 00:22:47,919

it would generate a differential current

695

00:22:51,430 --> 00:22:49,760

and the experimental evidence

696

00:22:52,789 --> 00:22:51,440

indicated that the differential current

697

00:22:54,149 --> 00:22:52,799

which was measured between different

698

00:22:57,430 --> 00:22:54,159

types of metals

699

00:22:59,350 --> 00:22:57,440

say tantalum versus hafnium

700

00:23:00,870 --> 00:22:59,360

tantalum versus or tantalum oxide were

701
00:23:01,510 --> 00:23:00,880
indeed different whereas if the metals

702
00:23:03,510 --> 00:23:01,520
were matched

703
00:23:04,870 --> 00:23:03,520
you saw lesser or no difference

704
00:23:06,710 --> 00:23:04,880
indicating that

705
00:23:08,310 --> 00:23:06,720
a second law or a differential current

706
00:23:10,149 --> 00:23:08,320
could be developed between

707
00:23:11,830 --> 00:23:10,159
two materials at thermal equilibrium but

708
00:23:13,510 --> 00:23:11,840
the thermal equilibrium had to be very

709
00:23:15,830 --> 00:23:13,520
high in terms of temperature so this is

710
00:23:17,430 --> 00:23:15,840
impractical

711
00:23:19,830 --> 00:23:17,440
the chemical steady state equinox

712
00:23:21,750 --> 00:23:19,840
equilibria

713
00:23:23,350 --> 00:23:21,760

works in the following way let's say you

714

00:23:26,470 --> 00:23:23,360

have some diatomic hydrogen

715

00:23:28,470 --> 00:23:26,480

H₂ and and you were to put diatomic

716

00:23:30,149 --> 00:23:28,480

hydrogen into a into an empty cavity

717

00:23:31,590 --> 00:23:30,159

which was made out of let's say surface

718

00:23:33,750 --> 00:23:31,600

type 2 all around

719

00:23:35,110 --> 00:23:33,760

and you have a piston which has surface

720

00:23:36,630 --> 00:23:35,120

type 2 on one side

721

00:23:38,070 --> 00:23:36,640

and a small patch of a different surface

722

00:23:39,270 --> 00:23:38,080

type let's say surface type one on the

723

00:23:41,590 --> 00:23:39,280

other

724

00:23:42,710 --> 00:23:41,600

now just for argument's sake let's say

725

00:23:44,710 --> 00:23:42,720

at a high temperature

726
00:23:46,630 --> 00:23:44,720
when these when diatomic hydrogen

727
00:23:48,710 --> 00:23:46,640
intersects and lands on the surface

728
00:23:49,669 --> 00:23:48,720
if it lands on surface two it simply

729
00:23:51,830 --> 00:23:49,679
bounces off or

730
00:23:53,510 --> 00:23:51,840
stays on the surface for a while and

731
00:23:55,590 --> 00:23:53,520
leaves as diatomic hydrogen

732
00:23:56,950 --> 00:23:55,600
and moreover if monoatomic hydrogen

733
00:23:57,590 --> 00:23:56,960
lands on the surface that skitters

734
00:23:59,909 --> 00:23:57,600
around

735
00:24:02,149 --> 00:23:59,919
finds itself forms diatomic hydrogen and

736
00:24:04,549 --> 00:24:02,159
then leaves

737
00:24:05,990 --> 00:24:04,559
on the other hand surface one let's say

738
00:24:06,950 --> 00:24:06,000

disassociates hydrogen so when a

739

00:24:09,190 --> 00:24:06,960

hydrogen

740

00:24:11,430 --> 00:24:09,200

molecule comes on it disassociates and

741

00:24:13,190 --> 00:24:11,440

comes off as two hydrogen atoms

742

00:24:14,870 --> 00:24:13,200

it's straightforward to show that under

743

00:24:16,630 --> 00:24:14,880

these conditions at thermal equilibrium

744

00:24:18,230 --> 00:24:16,640

if the mole molecules leave a thermal

745

00:24:19,909 --> 00:24:18,240

equilibrium from the surfaces

746

00:24:21,750 --> 00:24:19,919

that there will be a net pressure over

747

00:24:22,950 --> 00:24:21,760

surface one relative to surface two

748

00:24:25,909 --> 00:24:22,960

and there'll be a net pressure on this

749

00:24:27,350 --> 00:24:25,919

piston which can make it make it run

750

00:24:30,149 --> 00:24:27,360

this would be a way of extracting work

751
00:24:32,070 --> 00:24:30,159
from the heat bath this requires though

752
00:24:33,510 --> 00:24:32,080
that you have two different metals which

753
00:24:35,029 --> 00:24:33,520
have different propensities for

754
00:24:37,590 --> 00:24:35,039
disassociation

755
00:24:38,789 --> 00:24:37,600
of hydrogen 10 years ago i did

756
00:24:40,789 --> 00:24:38,799
experiments of

757
00:24:43,510 --> 00:24:40,799
with molybdenum and tungsten at high

758
00:24:45,110 --> 00:24:43,520
temperature around 2000 to 3000 kelvin

759
00:24:47,350 --> 00:24:45,120
in which i looked at the dissociation

760
00:24:47,909 --> 00:24:47,360
rate the amount of disassociation rate

761
00:24:54,230 --> 00:24:47,919
of

762
00:24:56,070 --> 00:24:54,240
versus molybdenum and indeed i saw

763
00:24:57,669 --> 00:24:56,080

distinct differences enough to actually

764

00:24:59,909 --> 00:24:57,679

drive a small

765

00:25:00,870 --> 00:24:59,919

low-power radiometer but again the

766

00:25:01,430 --> 00:25:00,880

experiments were done at high

767

00:25:03,510 --> 00:25:01,440

temperature

768

00:25:04,710 --> 00:25:03,520

and have no commercial interest and and

769

00:25:05,750 --> 00:25:04,720

have generated

770

00:25:08,390 --> 00:25:05,760

no interest from the scientific

771

00:25:10,390 --> 00:25:08,400

community okay which brings us

772

00:25:11,590 --> 00:25:10,400

brings me to the last of the challenges

773

00:25:12,830 --> 00:25:11,600

which my colleagues and i have been

774

00:25:15,830 --> 00:25:12,840

working on for roughly 10

775

00:25:16,870 --> 00:25:15,840

uh better part of 10 years now which

776

00:25:19,190 --> 00:25:16,880

deals with

777

00:25:20,630 --> 00:25:19,200

semiconductors and these have the most

778

00:25:21,350 --> 00:25:20,640

possible commercial application in my

779

00:25:23,430 --> 00:25:21,360

opinion

780

00:25:25,110 --> 00:25:23,440

aside maybe from some gas cycles that

781

00:25:26,870 --> 00:25:25,120

have been proposed ken round who will

782

00:25:28,070 --> 00:25:26,880

speak next will propose a gas cycle

783

00:25:30,630 --> 00:25:28,080

which could have very high power

784

00:25:34,230 --> 00:25:33,110

so let's talk about silicon devices

785

00:25:36,070 --> 00:25:34,240

everything all this all the

786

00:25:38,149 --> 00:25:36,080

semiconductor devices that you have

787

00:25:39,750 --> 00:25:38,159

in your at your disposal all your ipods

788

00:25:41,990 --> 00:25:39,760

on blackberries computers

789

00:25:42,950 --> 00:25:42,000

are all based on silicon but special

790

00:25:45,669 --> 00:25:42,960

kind of silicon

791

00:25:46,870 --> 00:25:45,679

silicon which is doped and i say doped

792

00:25:49,350 --> 00:25:46,880

that simply means

793

00:25:51,350 --> 00:25:49,360

that you have some a silicon lattice

794

00:25:53,190 --> 00:25:51,360

which has a small impurity in it

795

00:25:55,350 --> 00:25:53,200

of let's say one part and ten thousand

796

00:25:58,390 --> 00:25:55,360

one part in a million of something like

797

00:26:00,470 --> 00:25:58,400

phosphorus for in doping connected to

798

00:26:01,750 --> 00:26:00,480

another piece of silicon which might

799

00:26:03,909 --> 00:26:01,760

have what's called p

800

00:26:04,789 --> 00:26:03,919

doping which would have something like

801
00:26:06,950 --> 00:26:04,799
boron in it

802
00:26:08,549 --> 00:26:06,960
in a very small concentration when you

803
00:26:09,110 --> 00:26:08,559
put small amounts of impurity into

804
00:26:11,029 --> 00:26:09,120
silicon

805
00:26:13,269 --> 00:26:11,039
you change its electrical conductivity

806
00:26:15,269 --> 00:26:13,279
and electrical properties enormously

807
00:26:17,110 --> 00:26:15,279
so what could you imagine well with

808
00:26:19,990 --> 00:26:17,120
n-type doping you have a surplus

809
00:26:21,110 --> 00:26:20,000
or an excess of mobile electrons in this

810
00:26:23,110 --> 00:26:21,120
lattice

811
00:26:25,350 --> 00:26:23,120
in the p-type you have an excess of what

812
00:26:28,549 --> 00:26:25,360
are called positive holes

813
00:26:31,590 --> 00:26:28,559

so you can imagine that if you have this

814

00:26:33,510 --> 00:26:31,600

n and p type material joined that some

815

00:26:34,950 --> 00:26:33,520

of the electrons would diffuse over into

816

00:26:35,430 --> 00:26:34,960

the p-type material and some of the

817

00:26:37,750 --> 00:26:35,440

holes

818

00:26:39,190 --> 00:26:37,760

would diffuse into the n-type material

819

00:26:40,630 --> 00:26:39,200

now to give you an example of how that

820

00:26:41,830 --> 00:26:40,640

might be let's say we were to take

821

00:26:43,269 --> 00:26:41,840

all the men in this room and put them

822

00:26:44,149 --> 00:26:43,279

against and put them on this half of the

823

00:26:45,830 --> 00:26:44,159

room

824

00:26:48,070 --> 00:26:45,840

and tie them with bungee cords to the

825

00:26:49,510 --> 00:26:48,080

wall and put all the women on this side

826

00:26:50,630 --> 00:26:49,520

of the room and tie bungee cords on them

827

00:26:52,950 --> 00:26:50,640

to that wall

828

00:26:54,310 --> 00:26:52,960

now not men and women men and women are

829

00:26:56,149 --> 00:26:54,320

naturally going to intermingle

830

00:26:58,549 --> 00:26:56,159

so they will slowly slowly enter

831

00:27:00,149 --> 00:26:58,559

penetrate across the boundary

832

00:27:01,669 --> 00:27:00,159

but eventually they'll be arrested by

833

00:27:02,950 --> 00:27:01,679

the bungee cord but they'll be energy

834

00:27:05,110 --> 00:27:02,960

stored in those bungee cords

835

00:27:06,230 --> 00:27:05,120

and and in this case similar thing

836

00:27:08,710 --> 00:27:06,240

happens

837

00:27:10,390 --> 00:27:08,720

the electrons go to this side the holes

838

00:27:12,230 --> 00:27:10,400

migrate to this side but because of the

839

00:27:14,870 --> 00:27:12,240

charge imbalance of positive

840

00:27:16,390 --> 00:27:14,880

and negative charges in the lattice that

841

00:27:16,950 --> 00:27:16,400

the an electric field is formed which

842

00:27:19,909 --> 00:27:16,960

arrests

843

00:27:21,269 --> 00:27:19,919

further diffusion this is well known

844

00:27:23,029 --> 00:27:21,279

there is no argument about this this is

845

00:27:24,310 --> 00:27:23,039

called the depletion region of a semi of

846

00:27:26,230 --> 00:27:24,320

a pn diode

847

00:27:27,669 --> 00:27:26,240

and the electric fields that are

848

00:27:29,029 --> 00:27:27,679

sustained inside of here

849

00:27:30,470 --> 00:27:29,039

are on the order of something like 10 to

850

00:27:31,830 --> 00:27:30,480

the seventh volts per meter in other

851
00:27:32,470 --> 00:27:31,840
words 10 million volts per meter

852
00:27:34,950 --> 00:27:32,480
enormous

853
00:27:37,190 --> 00:27:34,960
voltages but the voltage drop is only

854
00:27:39,750 --> 00:27:37,200
about a half to one volt so fairly low

855
00:27:42,389 --> 00:27:39,760
voltage very high electric fields

856
00:27:44,950 --> 00:27:42,399
now imagine you took this pn diode and

857
00:27:47,990 --> 00:27:44,960
bent it like a pretzel

858
00:27:50,630 --> 00:27:48,000
here we have it again n-type built into

859
00:27:51,830 --> 00:27:50,640
a horseshoe pattern and a p-type

860
00:27:53,350 --> 00:27:51,840
similarly

861
00:27:54,549 --> 00:27:53,360
here we have the junction at the top

862
00:27:56,310 --> 00:27:54,559
where you have the diffusion of

863
00:27:57,830 --> 00:27:56,320

electrons and holes forming an electric

864

00:28:00,389 --> 00:27:57,840

field here

865

00:28:01,269 --> 00:28:00,399

at the bottom side though i have left an

866

00:28:04,950 --> 00:28:01,279

open

867

00:28:08,310 --> 00:28:04,960

vacuum gap where no electrons or holes

868

00:28:10,630 --> 00:28:08,320

can diffuse well it turns out that based

869

00:28:12,549 --> 00:28:10,640

on conservation of energy kirchhoff's

870

00:28:13,990 --> 00:28:12,559

loop rule or faraday's off one of

871

00:28:17,269 --> 00:28:14,000

maxwell's equations

872

00:28:19,750 --> 00:28:17,279

it's easy to show that if you take

873

00:28:20,870 --> 00:28:19,760

an electron or or a charge of any sort

874

00:28:23,669 --> 00:28:20,880

and move it around

875

00:28:24,870 --> 00:28:23,679

this loop if it starts here and goes up

876

00:28:26,310 --> 00:28:24,880

a potential

877

00:28:27,990 --> 00:28:26,320

and then comes around this loop and

878

00:28:28,470 --> 00:28:28,000

comes back to where it started it had

879

00:28:30,549 --> 00:28:28,480

better go

880

00:28:32,549 --> 00:28:30,559

down a certain potential drop as well

881

00:28:34,389 --> 00:28:32,559

somewhere else in this in this circuit

882

00:28:36,149 --> 00:28:34,399

so if you have a potential drop of of a

883

00:28:37,590 --> 00:28:36,159

volt here you have to have a potential

884

00:28:39,029 --> 00:28:37,600

rise somewhere else

885

00:28:40,230 --> 00:28:39,039

it can't be anywhere else in the bulk

886

00:28:41,750 --> 00:28:40,240

because if you did you'd have electric

887

00:28:43,830 --> 00:28:41,760

fields here which would cause currents

888

00:28:46,389 --> 00:28:43,840

therefore it can't be in the bulk it

889

00:28:49,269 --> 00:28:46,399

must be across the gap

890

00:28:49,909 --> 00:28:49,279

so you can make us an airtight analytic

891

00:28:52,630 --> 00:28:49,919

argument

892

00:28:53,110 --> 00:28:52,640

that beca that in a p in junction of

893

00:28:57,669 --> 00:28:53,120

this

894

00:28:59,190 --> 00:28:57,679

should have a very large electric field

895

00:29:00,710 --> 00:28:59,200

the voltage drop here has to be

896

00:29:01,590 --> 00:29:00,720

expressed as a voltage drop here in the

897

00:29:03,590 --> 00:29:01,600

opposite sense

898

00:29:05,190 --> 00:29:03,600

and as a result the electric field here

899

00:29:06,950 --> 00:29:05,200

can be quite intense

900

00:29:08,630 --> 00:29:06,960

the electric field here is usually

901
00:29:09,909 --> 00:29:08,640
smeared out over a distance of about a

902
00:29:11,590 --> 00:29:09,919
micron or so

903
00:29:13,510 --> 00:29:11,600
down here you can make it 100 times less

904
00:29:15,190 --> 00:29:13,520
if you wish by making this gap narrower

905
00:29:16,710 --> 00:29:15,200
in which case you can make the electric

906
00:29:18,310 --> 00:29:16,720
field enormous you can make it

907
00:29:21,029 --> 00:29:18,320
10 or 100 times greater than it is in

908
00:29:22,630 --> 00:29:21,039
here in doing so you can store

909
00:29:24,070 --> 00:29:22,640
electrostatic potential energy in the

910
00:29:25,430 --> 00:29:24,080
electric field those of you who do

911
00:29:27,830 --> 00:29:25,440
physics or electrical engineering

912
00:29:29,510 --> 00:29:27,840
know that a capacitor does just this a

913
00:29:31,190 --> 00:29:29,520

capacitor is a device which stores

914

00:29:33,750 --> 00:29:31,200

energy and charges or if you wish

915

00:29:34,789 --> 00:29:33,760

in electric field energy so this is a

916

00:29:37,190 --> 00:29:34,799

capacitor

917

00:29:38,310 --> 00:29:37,200

which is charged and is charged by

918

00:29:40,870 --> 00:29:38,320

thermal motion

919

00:29:43,269 --> 00:29:40,880

and is charged forever this is a

920

00:29:45,029 --> 00:29:43,279

thermally charged capacitor

921

00:29:47,430 --> 00:29:45,039

until you find some way maybe of

922

00:29:49,909 --> 00:29:47,440

exploiting that energy

923

00:29:51,909 --> 00:29:49,919

this is a simulation done with advanced

924

00:29:54,470 --> 00:29:51,919

semiconductor software from

925

00:29:55,590 --> 00:29:54,480

the bay area savaco international they

926
00:29:57,510 --> 00:29:55,600
conducted

927
00:29:59,510 --> 00:29:57,520
a number of simulations for us we did

928
00:30:00,710 --> 00:29:59,520
our own both our simulations agreed with

929
00:30:02,310 --> 00:30:00,720
each other they did theirs in an

930
00:30:03,990 --> 00:30:02,320
unbiased way and they found that indeed

931
00:30:04,549 --> 00:30:04,000
when you make an np type material and

932
00:30:06,149 --> 00:30:04,559
join them

933
00:30:07,990 --> 00:30:06,159
you see electric fields up here which

934
00:30:09,190 --> 00:30:08,000
are fairly weak on the order of ten to

935
00:30:09,909 --> 00:30:09,200
the fourth ten to the fifth volts per

936
00:30:11,830 --> 00:30:09,919
meter

937
00:30:13,190 --> 00:30:11,840
but in this gap you see enormously

938
00:30:14,630 --> 00:30:13,200

intense electric fields

939

00:30:16,630 --> 00:30:14,640

one's on the order of ten to the seventh

940

00:30:17,510 --> 00:30:16,640

volts per meter so this thermal

941

00:30:19,190 --> 00:30:17,520

capacitor

942

00:30:20,789 --> 00:30:19,200

has can be shown analytically it can be

943

00:30:23,029 --> 00:30:20,799

shown by numerical simulation

944

00:30:24,630 --> 00:30:23,039

and there's a lot of corroborative

945

00:30:25,909 --> 00:30:24,640

evidence from the solid state community

946

00:30:28,789 --> 00:30:25,919

that has already been measured

947

00:30:31,830 --> 00:30:28,799

experimentally as well

948

00:30:33,750 --> 00:30:31,840

so imagine what you might be able to do

949

00:30:36,549 --> 00:30:33,760

i'd like to imagine first a very simple

950

00:30:37,990 --> 00:30:36,559

device let's say we have

951
00:30:39,590 --> 00:30:38,000
something we'll call a hammer which is a

952
00:30:41,990 --> 00:30:39,600
movable um

953
00:30:43,830 --> 00:30:42,000
top of a capacitor just a metallic plate

954
00:30:44,549 --> 00:30:43,840
hooked to a spring with spring constant

955
00:30:48,310 --> 00:30:44,559
k

956
00:30:50,070 --> 00:30:48,320
supply power supply comes up and is

957
00:30:52,149 --> 00:30:50,080
hooked to the bottom part of this metal

958
00:30:53,909 --> 00:30:52,159
another metal plate across a vacuum gap

959
00:30:55,190 --> 00:30:53,919
and this is called the anvil

960
00:30:57,430 --> 00:30:55,200
now you can imagine the following

961
00:30:59,990 --> 00:30:57,440
happening this voltage power supply

962
00:31:01,110 --> 00:31:00,000
will charge up this could the side of

963
00:31:03,110 --> 00:31:01,120

the capacitor on this side of the

964

00:31:04,630 --> 00:31:03,120

capacitor positive here negative here

965

00:31:06,149 --> 00:31:04,640

and you'll have an attraction of the top

966

00:31:07,830 --> 00:31:06,159

plate against the bottom plate

967

00:31:08,950 --> 00:31:07,840

when they come together the chargers

968

00:31:10,070 --> 00:31:08,960

will annihilate each other

969

00:31:12,549 --> 00:31:10,080

instantaneously

970

00:31:14,230 --> 00:31:12,559

the capacitor will discharge but of

971

00:31:17,750 --> 00:31:14,240

course it has

972

00:31:19,909 --> 00:31:17,760

at that point um

973

00:31:21,590 --> 00:31:19,919

pulled on this spring which will retract

974

00:31:23,430 --> 00:31:21,600

back the hammer

975

00:31:25,110 --> 00:31:23,440

the hammer will recharge on the time

976
00:31:26,070 --> 00:31:25,120
scale set by the capacitance of these

977
00:31:27,669 --> 00:31:26,080
plates and the

978
00:31:29,990 --> 00:31:27,679
resistance of the resistor what's called

979
00:31:31,830 --> 00:31:30,000
the rc time constant

980
00:31:33,669 --> 00:31:31,840
now if the natural mechanical

981
00:31:36,149 --> 00:31:33,679
oscillation frequency of this hammer

982
00:31:36,789 --> 00:31:36,159
equals the time constant for the

983
00:31:39,590 --> 00:31:36,799
recharge

984
00:31:40,789 --> 00:31:39,600
you can imagine the the the top plate

985
00:31:42,389 --> 00:31:40,799
charging up

986
00:31:44,470 --> 00:31:42,399
being attracted down touching

987
00:31:47,430 --> 00:31:44,480
discharging being pulled back

988
00:31:48,310 --> 00:31:47,440

recharging being pulled back discharging

989

00:31:51,590 --> 00:31:48,320

being pulled back

990

00:31:53,110 --> 00:31:51,600

recharging basically forever

991

00:31:55,269 --> 00:31:53,120

this is called an electromechanical

992

00:31:57,350 --> 00:31:55,279

oscillator these are very common

993

00:31:59,350 --> 00:31:57,360

in technology in fact if you have an old

994

00:32:01,190 --> 00:31:59,360

regular quartz wrist watch

995

00:32:02,389 --> 00:32:01,200

this is an electromechanical oscillator

996

00:32:03,669 --> 00:32:02,399

so these are well known

997

00:32:05,509 --> 00:32:03,679

a student of mine and i built one of

998

00:32:06,950 --> 00:32:05,519

these things in the afternoon and one

999

00:32:08,549 --> 00:32:06,960

during one afternoon with a high volt

1000

00:32:09,990 --> 00:32:08,559

high voltage power supply and it worked

1001
00:32:11,110 --> 00:32:10,000
like a charm not probably not a problem

1002
00:32:13,110 --> 00:32:11,120
at all

1003
00:32:14,710 --> 00:32:13,120
but let's translate this now let's

1004
00:32:17,190 --> 00:32:14,720
translate this to a system

1005
00:32:18,310 --> 00:32:17,200
in which instead of having a power

1006
00:32:20,470 --> 00:32:18,320
supply here

1007
00:32:21,669 --> 00:32:20,480
creating the voltage we have depletion

1008
00:32:25,430 --> 00:32:21,679
regions between an n

1009
00:32:27,590 --> 00:32:25,440
and p semiconductor creating the voltage

1010
00:32:29,509 --> 00:32:27,600
in this case you have the same electric

1011
00:32:31,990 --> 00:32:29,519
field across this hammer

1012
00:32:32,549 --> 00:32:32,000
and anvil gap as you had here and if

1013
00:32:35,669 --> 00:32:32,559

these are

1014

00:32:36,389 --> 00:32:35,679

thin springs thin leaf cantilevers of

1015

00:32:38,549 --> 00:32:36,399

silicon

1016

00:32:40,310 --> 00:32:38,559

they would they would take the the place

1017

00:32:42,389 --> 00:32:40,320

of this mechanical spring

1018

00:32:44,549 --> 00:32:42,399

and you can and we've also devised ways

1019

00:32:46,389 --> 00:32:44,559

in in inserting resistances into these

1020

00:32:48,149 --> 00:32:46,399

lines to vary the resistance

1021

00:32:49,990 --> 00:32:48,159

in doing so you can make an

1022

00:32:51,909 --> 00:32:50,000

electromechanical oscillator

1023

00:32:53,750 --> 00:32:51,919

here which is equivalent to the

1024

00:32:55,990 --> 00:32:53,760

electromechanical oscillator here

1025

00:32:57,509 --> 00:32:56,000

the difference being this one is is

1026

00:33:00,549 --> 00:32:57,519

powered by the wall plug

1027

00:33:01,909 --> 00:33:00,559

or by by a coal burning plant and this

1028

00:33:05,669 --> 00:33:01,919

is powered by

1029

00:33:07,110 --> 00:33:05,679

the pn junction you can work out work

1030

00:33:08,950 --> 00:33:07,120

cycles for this and show that

1031

00:33:11,990 --> 00:33:08,960

um that that indeed you can make work

1032

00:33:14,710 --> 00:33:12,000

cycles out of this cantilever device

1033

00:33:17,269 --> 00:33:14,720

we built prototypes about a year ago of

1034

00:33:18,470 --> 00:33:17,279

a torsional version of this oscillator

1035

00:33:20,549 --> 00:33:18,480

which ran into problems during the

1036

00:33:21,269 --> 00:33:20,559

fabrication process we decided to back

1037

00:33:23,750 --> 00:33:21,279

up

1038

00:33:24,549 --> 00:33:23,760

and look at two-dimensional versions of

1039

00:33:26,789 --> 00:33:24,559

it

1040

00:33:28,070 --> 00:33:26,799

these are electron micrographs of

1041

00:33:29,830 --> 00:33:28,080

silicon chips which we just had

1042

00:33:33,269 --> 00:33:29,840

fabricated and finished last week

1043

00:33:35,110 --> 00:33:33,279

which incorporate various ideas which i

1044

00:33:37,509 --> 00:33:35,120

just discussed

1045

00:33:39,350 --> 00:33:37,519

here's a gap where you have p-type

1046

00:33:40,789 --> 00:33:39,360

silicon here n-type silicon here we will

1047

00:33:42,230 --> 00:33:40,799

be using kelvin probes to measure the

1048

00:33:43,909 --> 00:33:42,240

electric field in this gap

1049

00:33:45,430 --> 00:33:43,919

to see whether indeed the intense

1050

00:33:48,389 --> 00:33:45,440

electric fields that we predict

1051

00:33:49,029 --> 00:33:48,399

are there we have made cantilevers where

1052

00:33:51,909 --> 00:33:49,039

we have a

1053

00:33:53,509 --> 00:33:51,919

we have nnp type semiconductors offset

1054

00:33:55,110 --> 00:33:53,519

by a very narrow gap

1055

00:33:56,710 --> 00:33:55,120

and we will measure whether when we

1056

00:33:58,149 --> 00:33:56,720

close this gap mechanically whether we

1057

00:33:59,430 --> 00:33:58,159

see the discharge we predict

1058

00:34:01,590 --> 00:33:59,440

and when we pull it back that it

1059

00:34:04,830 --> 00:34:01,600

recharges if that happens

1060

00:34:06,789 --> 00:34:04,840

we are very close to making a full

1061

00:34:08,389 --> 00:34:06,799

three-dimensional second law of violator

1062

00:34:10,869 --> 00:34:08,399

in my opinion

1063

00:34:12,149 --> 00:34:10,879

we have apparatus built for tests of

1064

00:34:15,589 --> 00:34:12,159

these these are set up

1065

00:34:18,230 --> 00:34:15,599

at sandia national labs and we pursued

1066

00:34:19,829 --> 00:34:18,240

probably the next year or so so the

1067

00:34:20,869 --> 00:34:19,839

research status with regard to our

1068

00:34:22,230 --> 00:34:20,879

second law of work

1069

00:34:25,109 --> 00:34:22,240

we are we currently have second law of

1070

00:34:27,270 --> 00:34:25,119

diodes two-dimensional diodes in hand

1071

00:34:28,310 --> 00:34:27,280

and we'll be testing them the next um

1072

00:34:31,589 --> 00:34:28,320

during the summer

1073

00:34:33,669 --> 00:34:31,599

and we have plans um in process

1074

00:34:36,629 --> 00:34:33,679

to build 3-d torsional oscillators to

1075

00:34:39,990 --> 00:34:36,639

test the hypothesis

1076

00:34:41,430 --> 00:34:40,000

so in the end what what a number of

1077

00:34:43,430 --> 00:34:41,440

researchers and i propose

1078

00:34:45,750 --> 00:34:43,440

is that the second law although it is

1079

00:34:47,430 --> 00:34:45,760

now considered absolute

1080

00:34:48,629 --> 00:34:47,440

have a number of possible challenges

1081

00:34:49,990 --> 00:34:48,639

that have been leveled against it which

1082

00:34:51,190 --> 00:34:50,000

have received no response from the

1083

00:34:53,030 --> 00:34:51,200

scientific community

1084

00:34:54,230 --> 00:34:53,040

the community is silent and has found no

1085

00:34:57,829 --> 00:34:54,240

way to

1086

00:35:01,430 --> 00:35:00,150

refute these challenges and we but we

1087

00:35:01,990 --> 00:35:01,440

are now in the position where the burden

1088

00:35:05,109 --> 00:35:02,000

of proof falls

1089

00:35:07,109 --> 00:35:05,119

on us to do the experiment theorists do

1090

00:35:08,470 --> 00:35:07,119

not make truth nature has its truth

1091

00:35:10,069 --> 00:35:08,480

which we have to discover

1092

00:35:12,310 --> 00:35:10,079

so again as i said the second law is

1093

00:35:14,390 --> 00:35:12,320

inviolable until it is no longer

1094

00:35:16,150 --> 00:35:14,400

and there's our in our goal to change

1095

00:35:16,550 --> 00:35:16,160

the rules of not only the second laws

1096

00:35:19,750 --> 00:35:16,560

game

1097

00:35:28,829 --> 00:35:19,760

currently played

1098

00:35:28,839 --> 00:35:43,750

questions

1099

00:35:46,790 --> 00:35:45,349

there are two versions of the entropy

1100

00:35:48,630 --> 00:35:46,800

one is information

1101

00:35:50,630 --> 00:35:48,640

the other is emotion of particles

1102

00:35:51,589 --> 00:35:50,640

correct it's not obvious to me that they

1103

00:35:54,390 --> 00:35:51,599

are the same

1104

00:35:55,349 --> 00:35:54,400

right uh so can you comment on that and

1105

00:35:58,470 --> 00:35:55,359

also

1106

00:35:59,589 --> 00:35:58,480

would you say whether the work you're

1107

00:36:01,670 --> 00:35:59,599

doing

1108

00:36:03,030 --> 00:36:01,680

implicitly invalidates an actual demon

1109

00:36:05,190 --> 00:36:03,040

argument

1110

00:36:07,750 --> 00:36:05,200

okay sure um so let's let's back up the

1111

00:36:09,430 --> 00:36:07,760

maxwell demon as proposed by maxwell 140

1112

00:36:11,589 --> 00:36:09,440

years ago

1113

00:36:13,270 --> 00:36:11,599

was a thought experiment which basically

1114

00:36:16,230 --> 00:36:13,280

says can you

1115

00:36:17,510 --> 00:36:16,240

shepherd particles in by either by

1116

00:36:18,550 --> 00:36:17,520

temperature or location to create

1117

00:36:22,870 --> 00:36:18,560

pressure differentials

1118

00:36:23,510 --> 00:36:22,880

okay and it and the way maxwell proposed

1119

00:36:26,710 --> 00:36:23,520

it

1120

00:36:29,510 --> 00:36:26,720

and and

1121

00:36:31,510 --> 00:36:29,520

the the information theorists starting

1122

00:36:32,710 --> 00:36:31,520

back in the 1960s began to realize when

1123

00:36:33,910 --> 00:36:32,720

they were looking at computers

1124

00:36:35,109 --> 00:36:33,920

that indeed if you're going to have a

1125

00:36:36,790 --> 00:36:35,119

computer you have to do something with

1126
00:36:37,750 --> 00:36:36,800
your excess information if you want to

1127
00:36:41,030 --> 00:36:37,760
erase a bit

1128
00:36:42,630 --> 00:36:41,040
information

1129
00:36:45,030 --> 00:36:42,640
but that increases the entropy of the

1130
00:36:45,829 --> 00:36:45,040
universe so if you make a maxwell demon

1131
00:36:48,069 --> 00:36:45,839
in other words

1132
00:36:49,109 --> 00:36:48,079
a thinking one that records the position

1133
00:36:51,589 --> 00:36:49,119
of molecules

1134
00:36:52,550 --> 00:36:51,599
and and keeps track of them in some sort

1135
00:36:55,030 --> 00:36:52,560
of register

1136
00:36:56,310 --> 00:36:55,040
if it's going to do it in a cyclic way

1137
00:37:00,230 --> 00:36:56,320
then ultimately

1138
00:37:02,069 --> 00:37:00,240

it has to go back and forget what it

1139

00:37:03,750 --> 00:37:02,079

uh the previous cycle otherwise it's no

1140

00:37:04,550 --> 00:37:03,760

longer a cyclic process but in the very

1141

00:37:06,150 --> 00:37:04,560

process

1142

00:37:07,910 --> 00:37:06,160

of forgetting in other words erasing a

1143

00:37:09,030 --> 00:37:07,920

bit of information it creates a bit of

1144

00:37:11,190 --> 00:37:09,040

entropy

1145

00:37:12,870 --> 00:37:11,200

and that apparently is what finally

1146

00:37:14,310 --> 00:37:12,880

foils the maxwell demon

1147

00:37:16,390 --> 00:37:14,320

unfortunately many scientists have

1148

00:37:18,230 --> 00:37:16,400

conflated thinking maxwell demons

1149

00:37:19,670 --> 00:37:18,240

against ones which naturally

1150

00:37:20,950 --> 00:37:19,680

arranged themselves like the ones which

1151
00:37:21,670 --> 00:37:20,960
have been explored over the last 20

1152
00:37:24,150 --> 00:37:21,680
years

1153
00:37:25,510 --> 00:37:24,160
so the maxwell demon as it's currently

1154
00:37:26,630 --> 00:37:25,520
understood is basically a straw man

1155
00:37:27,589 --> 00:37:26,640
because it incorporates the thinking

1156
00:37:31,430 --> 00:37:27,599
creatures ours are

1157
00:37:33,349 --> 00:37:31,440
maxwell zombies they don't think okay

1158
00:37:34,950 --> 00:37:33,359
uh we actually have a fairly long time

1159
00:37:37,190 --> 00:37:34,960
for questions because

1160
00:37:38,390 --> 00:37:37,200
daniel ended ahead of schedule so before

1161
00:37:40,310 --> 00:37:38,400
we go to the next question

1162
00:37:41,589 --> 00:37:40,320
i would like to make one comment which

1163
00:37:43,430 --> 00:37:41,599

is that

1164

00:37:44,870 --> 00:37:43,440

uh i believe you gave a talk very

1165

00:37:46,950 --> 00:37:44,880

similar to this one about

1166

00:37:48,870 --> 00:37:46,960

two years ago and i'm personally a bit

1167

00:37:50,710 --> 00:37:48,880

disappointed that

1168

00:37:52,150 --> 00:37:50,720

in terms of experimental progress you

1169

00:37:53,349 --> 00:37:52,160

seem to be in about the same place you

1170

00:37:55,829 --> 00:37:53,359

were then

1171

00:37:56,470 --> 00:37:55,839

um actually that's not the case um uh uh

1172

00:37:58,230 --> 00:37:56,480

york we

1173

00:37:59,589 --> 00:37:58,240

have we have built some silicon devices

1174

00:38:01,430 --> 00:37:59,599

in the last two years

1175

00:38:03,430 --> 00:38:01,440

and um as they say in science it's all

1176

00:38:06,870 --> 00:38:03,440

about time and money

1177

00:38:09,589 --> 00:38:06,880

okay the

1178

00:38:10,710 --> 00:38:09,599

the question i had is that as those

1179

00:38:14,710 --> 00:38:10,720

those

1180

00:38:17,829 --> 00:38:14,720

thin strips of silicon are are

1181

00:38:20,390 --> 00:38:17,839

moved or stressed uh on a

1182

00:38:21,589 --> 00:38:20,400

cyclic basis you're going to get phil

1183

00:38:25,270 --> 00:38:21,599

you're going to get fatigued

1184

00:38:27,430 --> 00:38:25,280

setting in which is uh which is a

1185

00:38:28,790 --> 00:38:27,440

part of the second law you know it takes

1186

00:38:30,950 --> 00:38:28,800

energy to

1187

00:38:32,150 --> 00:38:30,960

do that but don't they don't they

1188

00:38:33,829 --> 00:38:32,160

finally fail

1189

00:38:35,910 --> 00:38:33,839

yeah and have you taken that into

1190

00:38:36,230 --> 00:38:35,920

account yes we have the there there are

1191

00:38:40,470 --> 00:38:36,240

three

1192

00:38:41,750 --> 00:38:40,480

these devices have have to satisfy first

1193

00:38:43,430 --> 00:38:41,760

of all you have to make a

1194

00:38:45,670 --> 00:38:43,440

electromechanical silicon device that

1195

00:38:46,310 --> 00:38:45,680

has um an equivalence basically between

1196

00:38:48,069 --> 00:38:46,320

the time

1197

00:38:49,190 --> 00:38:48,079

constant the electro the electric time

1198

00:38:50,790 --> 00:38:49,200

constant and the mechanical time

1199

00:38:53,109 --> 00:38:50,800

constant such that they coincide so you

1200

00:38:54,710 --> 00:38:53,119

get this electromechanical resonance

1201

00:38:56,470 --> 00:38:54,720

the second one is that the amount of

1202

00:38:59,109 --> 00:38:56,480

loss in the system in other words the

1203

00:39:02,230 --> 00:38:59,119

amount of damping in the system

1204

00:39:04,550 --> 00:39:02,240

from the springs has to be below that

1205

00:39:06,310 --> 00:39:04,560

the loss of the the mechanical losses

1206

00:39:09,190 --> 00:39:06,320

have to be less than the energy gain

1207

00:39:11,109 --> 00:39:09,200

during each cycle from from the motion

1208

00:39:12,630 --> 00:39:11,119

and that requires very high q high

1209

00:39:13,829 --> 00:39:12,640

quality factor springs

1210

00:39:15,829 --> 00:39:13,839

which is which is why we're using

1211

00:39:18,390 --> 00:39:15,839

silicon crystal it has you can make

1212

00:39:19,270 --> 00:39:18,400

um cues of an over 100 000 with with

1213

00:39:20,630 --> 00:39:19,280

silicon

1214

00:39:21,670 --> 00:39:20,640

and that is also important so we're

1215

00:39:22,310 --> 00:39:21,680

going to have to work in a cube regime

1216

00:39:24,790 --> 00:39:22,320

of around

1217

00:39:25,990 --> 00:39:24,800

um around a thousand or more so so

1218

00:39:27,270 --> 00:39:26,000

that's certainly the case we're working

1219

00:39:28,710 --> 00:39:27,280

in the linear regime or

1220

00:39:30,630 --> 00:39:28,720

where fatigue should not be a serious

1221

00:39:32,550 --> 00:39:30,640

factor and the third one has to do with

1222

00:39:33,990 --> 00:39:32,560

obstruction we have to have enough

1223

00:39:34,710 --> 00:39:34,000

pullback that it can overcome surface

1224

00:39:36,710 --> 00:39:34,720

diction we've

1225

00:39:37,910 --> 00:39:36,720

we have found regimes in which all three

1226

00:39:39,589 --> 00:39:37,920

of these can be can

1227

00:39:41,030 --> 00:39:39,599

can be satisfied mutually and so as far

1228

00:39:42,390 --> 00:39:41,040

as we know there is no

1229

00:39:46,630 --> 00:39:42,400

physical impediment to making one of

1230

00:39:52,150 --> 00:39:49,910

over here over here suppose

1231

00:39:54,390 --> 00:39:52,160

next year you violate the second law do

1232

00:39:55,270 --> 00:39:54,400

you have any idea how you would correct

1233

00:40:02,710 --> 00:39:55,280

it

1234

00:40:04,710 --> 00:40:02,720

um i think i did second the

1235

00:40:06,550 --> 00:40:04,720

entropy of the universe never decreases

1236

00:40:09,750 --> 00:40:06,560

except when it does

1237

00:40:13,030 --> 00:40:11,670

well the second i mean the whole point

1238

00:40:13,589 --> 00:40:13,040

is that the second law is an absolute

1239

00:40:15,750 --> 00:40:13,599

statement

1240

00:40:17,910 --> 00:40:15,760

it it says something that this is

1241

00:40:19,349 --> 00:40:17,920

impossible so what we're saying is that

1242

00:40:21,670 --> 00:40:19,359

in certain cases it isn't it's like

1243

00:40:23,510 --> 00:40:21,680

saying um pigs don't fly

1244

00:40:25,190 --> 00:40:23,520

pigs don't fly unless you load them on a

1245

00:40:27,190 --> 00:40:25,200

plane then they do

1246

00:40:29,270 --> 00:40:27,200

so it's it's a question of finding the

1247

00:40:31,990 --> 00:40:29,280

regimes in which it is applicable

1248

00:40:32,550 --> 00:40:32,000

um so the second law in its current

1249

00:40:34,069 --> 00:40:32,560

state

1250

00:40:35,589 --> 00:40:34,079

is absolutely true but if there are

1251
00:40:43,109 --> 00:40:35,599
exceptions to it then you have to throw

1252
00:40:46,150 --> 00:40:44,470
well i don't find that a good reason not

1253
00:40:48,230 --> 00:40:46,160
to pursue my research it's their problem

1254
00:40:50,470 --> 00:40:48,240
not mine

1255
00:40:51,910 --> 00:40:50,480
i mean i'm simply testing this law and i

1256
00:40:53,430 --> 00:40:51,920
and and there are enough theoretical

1257
00:40:55,190 --> 00:40:53,440
arguments now not just from me but from

1258
00:40:56,470 --> 00:40:55,200
dozens of other dozen other researchers

1259
00:40:57,750 --> 00:40:56,480
research groups indicate there are

1260
00:40:59,430 --> 00:40:57,760
probably problems with it

1261
00:41:01,589 --> 00:40:59,440
now think about it the second law was

1262
00:41:02,550 --> 00:41:01,599
discovered and was and was developed

1263
00:41:05,750 --> 00:41:02,560

around the idea

1264

00:41:06,390 --> 00:41:05,760

of steam engines 150 years ago and what

1265

00:41:07,990 --> 00:41:06,400

has happened

1266

00:41:09,589 --> 00:41:08,000

since then we have you know we have we

1267

00:41:12,150 --> 00:41:09,599

have we have pushed the boundaries

1268

00:41:12,950 --> 00:41:12,160

of of temperature from from nanokelvin

1269

00:41:14,309 --> 00:41:12,960

up to 100

1270

00:41:16,150 --> 00:41:14,319

up to a billion degrees in the

1271

00:41:17,910 --> 00:41:16,160

laboratory we have um

1272

00:41:19,670 --> 00:41:17,920

we have pushed the densities of

1273

00:41:20,950 --> 00:41:19,680

materials up by by implosion techniques

1274

00:41:22,470 --> 00:41:20,960

by a factor of 100

1275

00:41:23,430 --> 00:41:22,480

we have discovered quantum mechanics we

1276

00:41:25,190 --> 00:41:23,440

have disc we have discovered

1277

00:41:26,790 --> 00:41:25,200

superconductivity we've discovered

1278

00:41:28,470 --> 00:41:26,800

chaos theory special relativity general

1279

00:41:30,550 --> 00:41:28,480

relativity and

1280

00:41:32,230 --> 00:41:30,560

it and it is the only law that i'm aware

1281

00:41:35,349 --> 00:41:32,240

of that has not been updated

1282

00:41:37,030 --> 00:41:35,359

in 200 years and i s and my belief is

1283

00:41:38,630 --> 00:41:37,040

it probably needs to be updated and the

1284

00:41:40,230 --> 00:41:38,640

updating is basically to say it is no

1285

00:41:41,430 --> 00:41:40,240

longer absolute any more than the ideal

1286

00:41:44,309 --> 00:41:41,440

gas laws absolute

1287

00:41:45,829 --> 00:41:44,319

the ideal gas law is excellent a a very

1288

00:41:46,550 --> 00:41:45,839

good approximation but it is not

1289

00:41:47,910 --> 00:41:46,560

absolute

1290

00:41:50,069 --> 00:41:47,920

it's a good approximation i think the

1291

00:41:51,349 --> 00:41:50,079

second law i believe the second law will

1292

00:41:52,230 --> 00:41:51,359

ultimately turn out to be a very good

1293

00:41:54,870 --> 00:41:52,240

approximation

1294

00:41:56,150 --> 00:41:54,880

but not absolutely true two more brief

1295

00:41:59,349 --> 00:41:56,160

questions

1296

00:42:01,109 --> 00:41:59,359

um on the hammer anvil contact point yes

1297

00:42:03,430 --> 00:42:01,119

what keeps that from just forming yet

1298

00:42:04,470 --> 00:42:03,440

another diode or sort of like a p i n

1299

00:42:06,790 --> 00:42:04,480

diode with a little

1300

00:42:08,230 --> 00:42:06,800

vacuum layer yes it does but after the

1301

00:42:10,790 --> 00:42:08,240

first contact wouldn't there

1302

00:42:12,069 --> 00:42:10,800

okay no current no what happens is there

1303

00:42:13,670 --> 00:42:12,079

are two things happening

1304

00:42:15,670 --> 00:42:13,680

in fact you could slow this thing down

1305

00:42:16,230 --> 00:42:15,680

if you wished and actually stop it there

1306

00:42:18,230 --> 00:42:16,240

and form

1307

00:42:19,270 --> 00:42:18,240

a complete p and diode it takes certain

1308

00:42:21,349 --> 00:42:19,280

amount of time for it to form

1309

00:42:23,030 --> 00:42:21,359

okay it takes 100 nanoseconds or longer

1310

00:42:25,589 --> 00:42:23,040

if you have a resistive load on it

1311

00:42:27,109 --> 00:42:25,599

but when it when it touches and the and

1312

00:42:29,829 --> 00:42:27,119

the charges begin to diffuse the

1313

00:42:30,870 --> 00:42:29,839

electric field

1314

00:42:31,990 --> 00:42:30,880

because it's being because now the

1315

00:42:33,109 --> 00:42:32,000

electric field is extending over the

1316

00:42:34,790 --> 00:42:33,119

depletion region

1317

00:42:36,950 --> 00:42:34,800

but recall that electrostatic pressure

1318

00:42:38,390 --> 00:42:36,960

goes as epsilon not the permittivity of

1319

00:42:39,510 --> 00:42:38,400

free space divided by two times the

1320

00:42:41,589 --> 00:42:39,520

electric field squared it goes

1321

00:42:43,829 --> 00:42:41,599

quadratically as the electric field

1322

00:42:45,430 --> 00:42:43,839

so when the when the contact is made

1323

00:42:46,069 --> 00:42:45,440

even if you do get the formation of an

1324

00:42:47,829 --> 00:42:46,079

entire

1325

00:42:49,829 --> 00:42:47,839

p-n junction the electric field is

1326

00:42:51,430 --> 00:42:49,839

dropped by a factor of

1327

00:42:52,950 --> 00:42:51,440

10 therefore the pressure is dropped by

1328

00:42:57,670 --> 00:42:52,960

a factor of 100 and therefore the spring

1329

00:43:01,589 --> 00:43:00,069

you mentioned uh background fluctuations

1330

00:43:04,230 --> 00:43:01,599

briefly in one of your slides

1331

00:43:07,030 --> 00:43:04,240

yes within limits hasn't this already

1332

00:43:09,589 --> 00:43:07,040

been a violation of the second law