1
00:00:24,159 --> 00:00:16,080
[Music]

2
00:00:25,420 --> 00:00:24,169
I'd like to talk this morning about a

3
00:00:27,479 --> 00:00:25,430
set of experiments that have been

4
00:00:30,040 --> 00:00:27,489
conducted over the last several years

5
00:00:32,770 --> 00:00:30,050
which are probing the foundations of

6
00:00:34,450 --> 00:00:32,780
thermodynamics the experiments are

7
00:00:37,420 --> 00:00:34,460
conducted at high temperature roughly

8
00:00:39,430 --> 00:00:37,430
about 2,000 degrees using refractory

9
00:00:41,800 --> 00:00:39,440
metals like tungsten and rhenium in a

10
00:00:43,570 --> 00:00:41,810
hydrogen gas but to understand this

11
00:00:45,340 --> 00:00:43,580
experiment doesn't require much more

12
00:00:46,270 --> 00:00:45,350
than really a glass of water because the

13
00:00:48,910 --> 00:00:46,280

effect is similar

14
00:00:51,640 --> 00:00:48,920
so consider a glass of water in this

15
00:00:53,350 --> 00:00:51,650
room if you put it down you expect it to

16
00:00:56,500 --> 00:00:53,360
come to the temperature of the room and

17
00:00:58,120 --> 00:00:56,510
should stay that way forever but if the

18
00:01:02,650 --> 00:00:58,130
molecules in the room were to conspire

19
00:01:04,509 --> 00:01:02,660
to let's say cool this water down to 20

20
00:01:07,690 --> 00:01:04,519
degrees below where it was is now to

21
00:01:08,380 --> 00:01:07,700
around its freezing point and keep it

22
00:01:10,870 --> 00:01:08,390
there forever

23
00:01:12,819 --> 00:01:10,880
you'd think that's peculiar and it would

24
00:01:15,550 --> 00:01:12,829
be because it would violate the second

25
00:01:18,279 --> 00:01:15,560
law of thermodynamics the experiments

26
00:01:23,649 --> 00:01:18,289
I'd like to describe today are the

27
00:01:25,809 --> 00:01:23,659
analog of this at high temperature I'd

28
00:01:27,639 --> 00:01:25,819
like to acknowledge the following people

29
00:01:30,849 --> 00:01:27,649
who are involved in in these experiments

30
00:01:33,010 --> 00:01:30,859
and also this talk is dedicated to

31
00:01:34,239 --> 00:01:33,020
Garrett Modell and New York Dobyns for

32
00:01:36,309 --> 00:01:34,249
pestering me over the last several years

33
00:01:39,569 --> 00:01:36,319
to do these kinds of experiments so

34
00:01:42,760 --> 00:01:39,579
thank you at the bottom are two articles

35
00:01:44,440 --> 00:01:42,770
the first one is I mean foundations of

36
00:01:46,480 --> 00:01:44,450
physics from this year these these this

37
00:01:49,389 --> 00:01:46,490
describes the experiments in more detail

38
00:01:51,580 --> 00:01:49,399

and the article from Physical Review II

39
00:01:56,889 --> 00:01:51,590
describes the theory on on which the

40
00:01:58,989 --> 00:01:56,899
experiments are based now the second law

41
00:02:01,209 --> 00:01:58,999
of thermodynamics is has been called the

42
00:02:03,159 --> 00:02:01,219
supreme law of nature it has lots of

43
00:02:05,949 --> 00:02:03,169
formal definitions and a lot of

44
00:02:08,080 --> 00:02:05,959
colloquial ones as well the number of

45
00:02:10,089 --> 00:02:08,090
formal definitions a couple dozen at

46
00:02:11,920 --> 00:02:10,099
least ones that you may be familiar with

47
00:02:13,720 --> 00:02:11,930
are there are no perfect heat engines

48
00:02:16,690 --> 00:02:13,730
there are no perfect refrigerators for

49
00:02:18,130 --> 00:02:16,700
any spontaneous process in nature the

50
00:02:20,180 --> 00:02:18,140
entropy change of the universe can

51
00:02:23,610 --> 00:02:20,190
cannot be less than zero

52
00:02:25,740 --> 00:02:23,620
one cannot transform an amount of heat

53
00:02:28,110 --> 00:02:25,750
solely into work in a closed cycle these

54
00:02:30,089 --> 00:02:28,120
are formal definitions but in everyday

55
00:02:31,680 --> 00:02:30,099
life we also have our understanding of

56
00:02:35,759 --> 00:02:31,690
the second law because it governs our

57
00:02:37,650 --> 00:02:35,769
lives so for instance a mess tends to

58
00:02:40,619 --> 00:02:37,660
expand into the space available to it

59
00:02:45,360 --> 00:02:40,629
the only way to deal with a can of worms

60
00:02:47,940 --> 00:02:45,370
is to find a bigger can Murphy's Law in

61
00:02:48,330 --> 00:02:47,950
a sense is this anything can go wrong it

62
00:02:52,319 --> 00:02:48,340
will

63
00:02:54,660 --> 00:02:52,329

and it's corollary every all situations

64
00:02:57,059 --> 00:02:54,670
tend to progress from bad to worse

65
00:02:59,430 --> 00:02:57,069
and then you can say well everything

66
00:03:06,059 --> 00:02:59,440
degrades we're all going to die this is

67
00:03:07,890 --> 00:03:06,069
because of the second law now when it

68
00:03:11,160 --> 00:03:07,900
comes to the second law there is much at

69
00:03:13,470 --> 00:03:11,170
stake the reason why we spend so much

70
00:03:15,300 --> 00:03:13,480
money on energy in this world roughly

71
00:03:18,030 --> 00:03:15,310
20% of the world's economy is devoted to

72
00:03:21,839 --> 00:03:18,040
energy is because when we use it we lose

73
00:03:23,550 --> 00:03:21,849
it after it's done 99.9% of it gets

74
00:03:26,699 --> 00:03:23,560
turned into heat and we can't get it

75
00:03:28,500 --> 00:03:26,709
back for every energy transaction for

76
00:03:31,620 --> 00:03:28,510
macroscopic objects that we carry out we

77
00:03:33,000 --> 00:03:31,630
pay attacks based on the second law but

78
00:03:35,309 --> 00:03:33,010
in fact if you look at the amount of

79
00:03:37,650 --> 00:03:35,319
heat in the world and if you could break

80
00:03:40,140 --> 00:03:37,660
the second law or bend it you would have

81
00:03:43,140 --> 00:03:40,150
access to virtually unlimited amounts of

82
00:03:44,670 --> 00:03:43,150
energy for instance in this room the

83
00:03:47,250 --> 00:03:44,680
volume of the air in this room is about

84
00:03:50,190 --> 00:03:47,260
six thousand cubic meters or about 7,000

85
00:03:51,900 --> 00:03:50,200
kilograms of air in this room and the

86
00:03:53,640 --> 00:03:51,910
amount of thermal energy in this room is

87
00:03:56,640 --> 00:03:53,650
equivalent to several hundred pounds of

88
00:03:58,140 --> 00:03:56,650

TNT in terms of its just intrinsic

89
00:04:00,960 --> 00:03:58,150
energy but we can't get at it the

90
00:04:03,770 --> 00:04:00,970
thermal energy in this class of water is

91
00:04:06,000 --> 00:04:03,780
equivalent to roughly about five to ten

92
00:04:08,879 --> 00:04:06,010
milliliters of gasoline and that's true

93
00:04:11,069 --> 00:04:08,889
of everything the tables us the air the

94
00:04:13,170 --> 00:04:11,079
water everything around us is loaded

95
00:04:14,729 --> 00:04:13,180
with thermal energy if one looks at the

96
00:04:16,560 --> 00:04:14,739
thermal energy and the upper app in the

97
00:04:19,469 --> 00:04:16,570
atmosphere the oceans in the upper crust

98
00:04:21,750 --> 00:04:19,479
is equivalent to roughly about 10,000

99
00:04:25,080 --> 00:04:21,760
times the entire fossil fuel reserves in

100
00:04:27,779 --> 00:04:25,090
the world not only that but if energy

101
00:04:30,510 --> 00:04:27,789
can be recycled in other words bending

102
00:04:32,670 --> 00:04:30,520
the second law then this energy would

103
00:04:35,619 --> 00:04:32,680
become recyclable and therefore

104
00:04:40,070 --> 00:04:38,240
now the second law has a mystique about

105
00:04:41,719 --> 00:04:40,080
it which is which has been around almost

106
00:04:43,550 --> 00:04:41,729
since its beginning certainly over the

107
00:04:45,860 --> 00:04:43,560
last hundred years and it can be summed

108
00:04:47,540 --> 00:04:45,870
up largely in the words of Arthur

109
00:04:48,980 --> 00:04:47,550
Eddington when he says that if your

110
00:04:51,200 --> 00:04:48,990
theory is found to be against the second

111
00:04:54,200 --> 00:04:51,210
law I can give you no hope but for to

112
00:04:57,140 --> 00:04:54,210
collapse in deepest humiliation this is

113
00:05:02,360 --> 00:04:57,150

this was 85 years ago and as the second

114
00:05:04,520 --> 00:05:02,370
law says all things change in the last

115
00:05:06,409 --> 00:05:04,530
twenty to twenty-five years there's been

116
00:05:07,909 --> 00:05:06,419
a revolution with regard to the second

117
00:05:10,969 --> 00:05:07,919
law in the mainstream scientific

118
00:05:13,550 --> 00:05:10,979
literature there had been roughly 25

119
00:05:15,770 --> 00:05:13,560
challenges posed more than 25 challenges

120
00:05:18,680 --> 00:05:15,780
posed in over 70 refereed articles and

121
00:05:19,969 --> 00:05:18,690
some of the best journals in physics in

122
00:05:21,950 --> 00:05:19,979
fact there have been more challenges

123
00:05:26,629 --> 00:05:21,960
over the last 20 years than there been

124
00:05:28,580 --> 00:05:26,639
over the last 200 years at the

125
00:05:29,570 --> 00:05:28,590
University of San Diego my colleagues

126
00:05:31,730 --> 00:05:29,580
and I have worked on a number of

127
00:05:33,920 --> 00:05:31,740
challenges which involve plasma physics

128
00:05:36,499 --> 00:05:33,930
um gravitational physics chemical

129
00:05:38,980 --> 00:05:36,509
physics solid-state physics and one I'll

130
00:05:41,600 --> 00:05:38,990
describe today deals with experiments in

131
00:05:43,459 --> 00:05:41,610
chemical physics and there'll be two

132
00:05:45,110 --> 00:05:43,469
experiments which I mutually reinforce

133
00:05:47,809 --> 00:05:45,120
each other which I'd like to describe

134
00:05:52,100 --> 00:05:47,819
the first involves filaments of tungsten

135
00:05:54,529 --> 00:05:52,110
and rhenium in hydrogen gas and secondly

136
00:05:56,930 --> 00:05:54,539
black body cavity experiments also known

137
00:05:59,809 --> 00:05:56,940
as Duncan's paradox which was proposed

138
00:06:01,219 --> 00:05:59,819

about 15 years ago now for those of you

139
00:06:03,800 --> 00:06:01,229
don't know what a black body cavity is

140
00:06:05,959 --> 00:06:03,810
is just a closed in tank container that

141
00:06:08,629 --> 00:06:05,969
is at one temperature that's a black

142
00:06:10,730 --> 00:06:08,639
body cavity and so just inside of a

143
00:06:12,800 --> 00:06:10,740
stove inside of this room if you are

144
00:06:14,839 --> 00:06:12,810
ready to settle down to one temperature

145
00:06:19,010 --> 00:06:14,849
anything can be a black body cavity it's

146
00:06:20,149 --> 00:06:19,020
defined simply by temperature so to get

147
00:06:23,959 --> 00:06:20,159
started let's talk a little bit about

148
00:06:25,909 --> 00:06:23,969
gas phase equilibrium if you take a diet

149
00:06:28,939 --> 00:06:25,919
I'm an archetypal reaction like a

150
00:06:31,610 --> 00:06:28,949
diatomic molecule a - it will be in

151
00:06:35,649 --> 00:06:31,620
equilibrium in a gas phase with its

152
00:06:37,760 --> 00:06:35,659
monomer the monomer or the atom a and

153
00:06:39,529 --> 00:06:37,770
they go back and forth and dynamic

154
00:06:41,180 --> 00:06:39,539
equilibrium and the company there is a

155
00:06:43,730 --> 00:06:41,190
constant for disassociation and a

156
00:06:45,320 --> 00:06:43,740
constant for recombination and the

157
00:06:46,370 --> 00:06:45,330
equilibrium constant when everything

158
00:06:48,520 --> 00:06:46,380
settles down at a given

159
00:06:50,840 --> 00:06:48,530
and pressure will be given by the

160
00:06:52,520 --> 00:06:50,850
concentration of the atom squared

161
00:06:54,950 --> 00:06:52,530
divided by the concentration of the

162
00:06:57,980 --> 00:06:54,960
dimer and that can also be related to

163
00:07:03,770 --> 00:06:57,990

the Gibbs free energy Delta G divided by

164
00:07:05,870 --> 00:07:03,780
RT which is the thermal energy now the

165
00:07:07,550 --> 00:07:05,880
simplest kinds of reactions are ones in

166
00:07:09,350 --> 00:07:07,560
which you basically have four processes

167
00:07:11,930 --> 00:07:09,360
adsorption where molecules come in and

168
00:07:14,480 --> 00:07:11,940
stick onto a surface where they desorb

169
00:07:17,090 --> 00:07:14,490
or leave the surface where they on the

170
00:07:19,400 --> 00:07:17,100
surface they can disassociate molecules

171
00:07:22,580 --> 00:07:19,410
into atoms and then recombination where

172
00:07:24,860 --> 00:07:22,590
the atoms recombine into molecules and

173
00:07:29,060 --> 00:07:24,870
these and these processes can also occur

174
00:07:32,510 --> 00:07:29,070
in the gas phase so if one has a gas and

175
00:07:34,900 --> 00:07:32,520
a surface one gets when things things

176
00:07:37,070 --> 00:07:34,910
settle down what is called a gas surface

177
00:07:39,440 --> 00:07:37,080
equilibrium where you have a constant

178
00:07:41,210 --> 00:07:39,450
regeneration of atoms and molecules on

179
00:07:42,470 --> 00:07:41,220
the surface in the gas phase where

180
00:07:45,350 --> 00:07:42,480
they're coming back and forth from the

181
00:07:48,320 --> 00:07:45,360
surface each all species and turning

182
00:07:52,220 --> 00:07:48,330
back between molecules and atoms in the

183
00:07:55,760 --> 00:07:52,230
gas and surface phase but if you make

184
00:07:58,310 --> 00:07:55,770
the gas diffuse enough such that gas

185
00:08:02,930 --> 00:07:58,320
phase conflict the gas phase collisions

186
00:08:05,390 --> 00:08:02,940
are rare then you lose the equilibrium

187
00:08:09,200 --> 00:08:05,400
of the gas phase those reactions are no

188
00:08:11,360 --> 00:08:09,210

longer feasible and as a result the gas

189
00:08:13,550 --> 00:08:11,370
phase is determined by what happens on

190
00:08:16,400 --> 00:08:13,560
the surface and what comes on and off

191
00:08:19,940 --> 00:08:16,410
the surface and this particular steady

192
00:08:22,820 --> 00:08:19,950
state non equilibrium and it's described

193
00:08:24,650 --> 00:08:22,830
in the fizzy paper at the top and is

194
00:08:27,590 --> 00:08:24,660
well-known in the physics community

195
00:08:29,180 --> 00:08:27,600
through things like QED plasmas and in

196
00:08:32,930 --> 00:08:29,190
the hydrogen reactions which I'll

197
00:08:35,810 --> 00:08:32,940
describe now the paradox upon which

198
00:08:37,940 --> 00:08:35,820
these reactions are these experiments

199
00:08:41,480 --> 00:08:37,950
are based were proposed by Todd Duncan

200
00:08:43,130 --> 00:08:41,490
about 15 years ago and they involve at

201
00:08:44,420 --> 00:08:43,140
first approximation what's called a

202
00:08:45,800 --> 00:08:44,430
Radiometer which many of you have played

203
00:08:48,590 --> 00:08:45,810
with as children which is basically a

204
00:08:51,380 --> 00:08:48,600
partially evacuated glass bulb that has

205
00:08:53,360 --> 00:08:51,390
a series of vanes one on one side black

206
00:08:55,850 --> 00:08:53,370
one side white when it's exposed to

207
00:08:58,329 --> 00:08:55,860
light the black side gets hot the white

208
00:09:00,269 --> 00:08:58,339
side stays relatively cool and

209
00:09:01,619 --> 00:09:00,279
effectively a gas pressure

210
00:09:03,689 --> 00:09:01,629
difference between the two sides of the

211
00:09:05,699 --> 00:09:03,699
vein caused it to turn how many how many

212
00:09:07,739 --> 00:09:05,709
of you have played with radiometers okay

213
00:09:09,869 --> 00:09:07,749

so you know what I'm talking about this

214
00:09:14,040 --> 00:09:09,879
experiment can be reduced to a

215
00:09:15,749 --> 00:09:14,050
Radiometer so let's look at the gas

216
00:09:18,329 --> 00:09:15,759
surface interactions for the two

217
00:09:21,199 --> 00:09:18,339
surfaces that we're interested in will

218
00:09:24,410 --> 00:09:21,209
have surface 2 s 2 and surface 1 s 1

219
00:09:28,499 --> 00:09:24,420
surface 2 tends to suppress

220
00:09:30,749 --> 00:09:28,509
disassociation so one has atoms come in

221
00:09:32,040 --> 00:09:30,759
a two A's come into the surface and

222
00:09:34,199 --> 00:09:32,050
leave out a 2

223
00:09:36,480 --> 00:09:34,209
whereas a 2 molecules come in and

224
00:09:39,629 --> 00:09:36,490
basically leave as they came so this

225
00:09:41,910 --> 00:09:39,639
actually promotes recombination and the

226
00:09:46,499 --> 00:09:41,920
s 1 surface suppresses recombination and

227
00:09:48,119 --> 00:09:46,509
tends to enhance disassociation so if

228
00:09:50,009 --> 00:09:48,129
one were to create a Radiometer out of

229
00:09:52,530 --> 00:09:50,019
this in a closed black body cavity with

230
00:09:54,629 --> 00:09:52,540
your with your radiometer veins s 1 and

231
00:09:57,749 --> 00:09:54,639
s 2 you would have a higher pressure on

232
00:10:00,210 --> 00:09:57,759
s 1 then on s 2 and that would cause the

233
00:10:03,269 --> 00:10:00,220
veins to turn and in principle lift a

234
00:10:05,100 --> 00:10:03,279
weight now if it lifts a weight but it

235
00:10:06,629 --> 00:10:05,110
does so in steady state in other words

236
00:10:08,610 --> 00:10:06,639
if these reactions are a steady state

237
00:10:10,559 --> 00:10:08,620
non equilibrium then it could lift the

238
00:10:12,299 --> 00:10:10,569

weight forever and keep getting work out

239
00:10:13,889 --> 00:10:12,309
of the system but the only place where

240
00:10:15,059 --> 00:10:13,899
that energy can come from if one thought

241
00:10:17,309 --> 00:10:15,069
satisfies the first law of

242
00:10:20,129 --> 00:10:17,319
thermodynamics is from the heat of the

243
00:10:22,199 --> 00:10:20,139
heat bath that surrounds the system this

244
00:10:24,540 --> 00:10:22,209
is a violation of the second law of

245
00:10:27,179 --> 00:10:24,550
thermodynamics this kind of radiometer

246
00:10:30,269 --> 00:10:27,189
can't exist which means that all

247
00:10:34,199 --> 00:10:30,279
surfaces must behave the same with

248
00:10:36,540 --> 00:10:34,209
respect to gas phase reactions but

249
00:10:39,670 --> 00:10:36,550
that's not true

250
00:10:41,620 --> 00:10:39,680
now you can also repose Duncans paradox

251
00:10:44,290 --> 00:10:41,630
in terms of a temperature version where

252
00:10:47,800 --> 00:10:44,300
one sets up a chemical cycle so to speak

253
00:10:50,110 --> 00:10:47,810
on surface one one starts with a two and

254
00:10:53,350 --> 00:10:50,120
it goes to two a atoms which then leave

255
00:10:56,080 --> 00:10:53,360
cycled up to the upper surface s2 which

256
00:10:58,060 --> 00:10:56,090
where they recombine into molecules and

257
00:10:59,530 --> 00:10:58,070
then come back down and because of the

258
00:11:01,420 --> 00:10:59,540
disassociation reaction is endothermic

259
00:11:04,180 --> 00:11:01,430
which means that it takes energy to

260
00:11:06,520 --> 00:11:04,190
break this molecule s1 will tend to cool

261
00:11:09,280 --> 00:11:06,530
and s2 because it's receiving that

262
00:11:11,110 --> 00:11:09,290
chemical energy will tend to heat that

263
00:11:13,300 --> 00:11:11,120

means that you can establish a set a

264
00:11:14,860 --> 00:11:13,310
steady state temperature differential

265
00:11:17,020 --> 00:11:14,870
between these two surfaces that should

266
00:11:18,670 --> 00:11:17,030
not go away but as soon as you have a

267
00:11:21,840 --> 00:11:18,680
temperature differential you have the

268
00:11:24,670 --> 00:11:21,850
means to run a heat engine perpetually

269
00:11:26,290 --> 00:11:24,680
which again is violet which violates the

270
00:11:28,870 --> 00:11:26,300
second law so this should not be allowed

271
00:11:30,580 --> 00:11:28,880
and that all turns on whether all

272
00:11:33,000 --> 00:11:30,590
surfaces act the same with respect to

273
00:11:35,410 --> 00:11:33,010
the gas or whether they can be different

274
00:11:37,510 --> 00:11:35,420
so the experiments I'd like to describe

275
00:11:39,520 --> 00:11:37,520
our experiments which actually

276
00:11:42,070 --> 00:11:39,530
demonstrate that different kinds of

277
00:11:44,410 --> 00:11:42,080
surfaces do perform differently in terms

278
00:11:46,060 --> 00:11:44,420
of disassociation and recombination with

279
00:11:48,280 --> 00:11:46,070
respect to a gas in particular hydrogen

280
00:11:50,830 --> 00:11:48,290
so the first set of experiments are a

281
00:11:53,650 --> 00:11:50,840
two filament comparison between tungsten

282
00:11:56,500 --> 00:11:53,660
and rhenium these are the dimensions of

283
00:11:58,360 --> 00:11:56,510
the various items what you're seeing are

284
00:12:01,480 --> 00:11:58,370
two copper electrodes and between them

285
00:12:03,460 --> 00:12:01,490
are strung to planar filaments of

286
00:12:05,920 --> 00:12:03,470
identical dimensions thicknesses and so

287
00:12:07,420 --> 00:12:05,930
on one is made out of look the the near

288
00:12:10,420 --> 00:12:07,430

one is made out of rhenium the far one

289
00:12:14,200 --> 00:12:10,430
tungsten the temperatures were run

290
00:12:16,210 --> 00:12:14,210
between about 2100 Kelvin and the gases

291
00:12:17,830 --> 00:12:16,220
that were run first vacuum than helium

292
00:12:21,730 --> 00:12:17,840
and hydrogen and the reasons for this

293
00:12:23,920 --> 00:12:21,740
will be explained in a moment here's a

294
00:12:25,510 --> 00:12:23,930
schematic of the experiment it consists

295
00:12:28,420 --> 00:12:25,520
of a vacuum vessel with base pressure of

296
00:12:30,070 --> 00:12:28,430
about 10 to the minus 6 Torr and the two

297
00:12:32,260 --> 00:12:30,080
filaments are basically resistors which

298
00:12:33,970 --> 00:12:32,270
are heated by power supplies matched

299
00:12:36,190 --> 00:12:33,980
power supplies and calibrated power

300
00:12:38,140 --> 00:12:36,200
supplies and then looked upon by optical

301
00:12:42,760 --> 00:12:38,150
pyrometers which which monitor their

302
00:12:44,800 --> 00:12:42,770
temperatures now in order to determine

303
00:12:46,840 --> 00:12:44,810
how well each of these disassociates

304
00:12:49,390 --> 00:12:46,850
hydrogen you need to do a comparison and

305
00:12:49,810 --> 00:12:49,400
the first thing and this is a pot of the

306
00:12:52,120 --> 00:12:49,820
film

307
00:12:53,470 --> 00:12:52,130
power in watts that's much how much the

308
00:12:55,300 --> 00:12:53,480
electrical power needs to be put through

309
00:12:57,880 --> 00:12:55,310
the filament in order to hold its

310
00:12:59,350 --> 00:12:57,890
temperature at a given value so for

311
00:13:01,570 --> 00:12:59,360
instance if you just let the filaments

312
00:13:03,640 --> 00:13:01,580
sit there and in the room it will just

313
00:13:05,110 --> 00:13:03,650

sit there at around 300 Kelvin but if

314
00:13:07,570 --> 00:13:05,120
you wish to bring it up to a thousand or

315
00:13:09,550 --> 00:13:07,580
1500 or 2000 Kelvin as indicated by the

316
00:13:11,310 --> 00:13:09,560
lower axis you have to put electrical

317
00:13:14,260 --> 00:13:11,320
power through it but once you do that

318
00:13:16,750 --> 00:13:14,270
that power will start being lost to the

319
00:13:19,690 --> 00:13:16,760
walls of your vessel in the first case

320
00:13:22,360 --> 00:13:19,700
the power sub vac is the amount of power

321
00:13:24,550 --> 00:13:22,370
necessary to hold the temperature in a

322
00:13:26,830 --> 00:13:24,560
vacuum and let's say we want to hold it

323
00:13:29,050 --> 00:13:26,840
at 2,000 degrees then we have to invest

324
00:13:31,060 --> 00:13:29,060
power into that filament to offset the

325
00:13:32,740 --> 00:13:31,070
radiation losses by blackbody radiation

326
00:13:34,720 --> 00:13:32,750
from the hot filament it's glowing as

327
00:13:36,310 --> 00:13:34,730
hot as a light bulb and also the

328
00:13:40,090 --> 00:13:36,320
conduction conductive losses to the

329
00:13:42,280 --> 00:13:40,100
electrodes now once we enter we put in a

330
00:13:43,840 --> 00:13:42,290
certain pressure of helium now we have

331
00:13:44,710 --> 00:13:43,850
another loss channel which means we have

332
00:13:46,060 --> 00:13:44,720
to put in more chant

333
00:13:48,970 --> 00:13:46,070
more power to hold the same temperature

334
00:13:51,210 --> 00:13:48,980
that loss channel power loss channel is

335
00:13:53,980 --> 00:13:51,220
convection of hot helium to the walls

336
00:13:55,630 --> 00:13:53,990
now helium and tunc sand and hydrogen

337
00:13:57,250 --> 00:13:55,640
have basically the same thermal

338
00:13:59,740 --> 00:13:57,260

conductivity within about 10 or 20

339
00:14:03,280 --> 00:13:59,750
percent and so if you now put in

340
00:14:04,420 --> 00:14:03,290
hydrogen the extra power you put in in

341
00:14:06,970 --> 00:14:04,430
order to hold the temperature in a

342
00:14:09,910 --> 00:14:06,980
hydrogen gas at the same pressure that

343
00:14:12,190 --> 00:14:09,920
you had done it at helium corresponds to

344
00:14:14,110 --> 00:14:12,200
the amount of energy that's going into

345
00:14:17,620 --> 00:14:14,120
disassociating those hydrogen molecules

346
00:14:19,480 --> 00:14:17,630
on the surface so if one does an

347
00:14:22,380 --> 00:14:19,490
experiment now and compares the amount

348
00:14:26,320 --> 00:14:22,390
of power necessary the hydrogen

349
00:14:28,480 --> 00:14:26,330
disassociation power in watts between

350
00:14:29,920 --> 00:14:28,490
that of tungsten and rhenium you find

351
00:14:31,930 --> 00:14:29,930
that once you get to the temperature at

352
00:14:34,300 --> 00:14:31,940
which disassociation occurs around 1500

353
00:14:35,740 --> 00:14:34,310
Kelvin these two surfaces begin to

354
00:14:36,970 --> 00:14:35,750
deviate in an amount of in the amount of

355
00:14:38,800 --> 00:14:36,980
power necessary to hold their

356
00:14:40,420 --> 00:14:38,810
temperatures which means the amount of

357
00:14:42,310 --> 00:14:40,430
hydrogen that they're disassociating and

358
00:14:46,210 --> 00:14:42,320
identical pressures and temperatures are

359
00:14:48,550 --> 00:14:46,220
different therefore you based on this

360
00:14:51,370 --> 00:14:48,560
you can see that rhenium disassociates

361
00:14:53,470 --> 00:14:51,380
hydrogen much better than tungsten but

362
00:14:57,850 --> 00:14:53,480
once you agree to that you set up the

363
00:15:00,840 --> 00:14:57,860

conditions for Duncans paradox here is a

364
00:15:03,840 --> 00:15:00,850
plot of the differential hydrogen

365
00:15:06,070 --> 00:15:03,850
disassociation power in watts

366
00:15:08,440 --> 00:15:06,080
pressure versus temperature on the

367
00:15:11,080 --> 00:15:08,450
horizontal axis is the logarithm of the

368
00:15:12,640 --> 00:15:11,090
pressure ranging from a 1/10 of a tour

369
00:15:16,450 --> 00:15:12,650
or about a ten thousandth of an

370
00:15:20,890 --> 00:15:16,460
atmosphere of hydrogen up to about 10

371
00:15:22,660 --> 00:15:20,900
Torr or about 100 and atmosphere and if

372
00:15:24,880 --> 00:15:22,670
one goes in the vertical axis one has

373
00:15:27,250 --> 00:15:24,890
the temperature one notice that the temp

374
00:15:29,050 --> 00:15:27,260
that the that the that there's a red

375
00:15:30,730 --> 00:15:29,060
zone here which indicates and the upper

376
00:15:36,180 --> 00:15:30,740
temperature range it takes a great deal

377
00:15:38,620 --> 00:15:36,190
more power to disassociate to keep the

378
00:15:41,380 --> 00:15:38,630
rhenium film at hot than the tungsten

379
00:15:44,350 --> 00:15:41,390
one if one normalizes this to pressure

380
00:15:46,870 --> 00:15:44,360
one finds the activity up in the upper

381
00:15:50,320 --> 00:15:46,880
left corner which indicates that at

382
00:15:51,700 --> 00:15:50,330
lower pressures the relative difference

383
00:15:54,820 --> 00:15:51,710
between rhenium and tungsten become

384
00:15:57,730 --> 00:15:54,830
accentuated so the filament experiments

385
00:16:00,100 --> 00:15:57,740
show the following both hydrogen both

386
00:16:02,290 --> 00:16:00,110
tungsten and rhenium demonstrate non

387
00:16:03,640 --> 00:16:02,300
equilibrium hydrogen concentrations 10

388
00:16:05,650 --> 00:16:03,650

to 100 times higher than you can expect

389
00:16:07,240 --> 00:16:05,660
from gas phase equilibrium and they're

390
00:16:09,280 --> 00:16:07,250
also distinct from each other by almost

391
00:16:11,260 --> 00:16:09,290
a factor of two but there's a loophole

392
00:16:12,700 --> 00:16:11,270
here this does not violate the second

393
00:16:15,280 --> 00:16:12,710
law because this is not a black body

394
00:16:18,450 --> 00:16:15,290
cavity of configuration so let's go to

395
00:16:20,650 --> 00:16:18,460
that here is Duncan Duncan's paradox

396
00:16:23,740 --> 00:16:20,660
results again are found in foundations

397
00:16:26,200 --> 00:16:23,750
of physics from this year again we have

398
00:16:28,990 --> 00:16:26,210
a vacuum vessel housing a black body

399
00:16:30,579 --> 00:16:29,000
cavity cylinder which is heated by ohmic

400
00:16:33,190 --> 00:16:30,589
heating inside of which there are two

401
00:16:34,960 --> 00:16:33,200
thermocouples type C thermocouples one

402
00:16:38,320 --> 00:16:34,970
coated with rhenium one coated with

403
00:16:40,630 --> 00:16:38,330
tungsten here's the inside of the black

404
00:16:43,300 --> 00:16:40,640
body cavity uranium coated and tungsten

405
00:16:45,160 --> 00:16:43,310
coated thermocouples this the inverse of

406
00:16:48,970 --> 00:16:45,170
this was also carried out in which we

407
00:16:52,630 --> 00:16:48,980
had a rhenium black body cavity rather

408
00:16:54,220 --> 00:16:52,640
than a tungsten one here again is the

409
00:16:56,110 --> 00:16:54,230
experimental apparatus on the left is

410
00:16:58,510 --> 00:16:56,120
the black body cylinder at the center

411
00:17:01,660 --> 00:16:58,520
the elec the Holding apparatus is the

412
00:17:03,520 --> 00:17:01,670
copper and on the right the assembly is

413
00:17:06,460 --> 00:17:03,530

that before it goes into the vacuum

414
00:17:07,720 --> 00:17:06,470
chamber now if one looks at the

415
00:17:08,980 --> 00:17:07,730
differential temperature between the

416
00:17:11,980 --> 00:17:08,990
tungsten and rhenium under these

417
00:17:16,990 --> 00:17:11,990
circumstances if one looks from about

418
00:17:17,470 --> 00:17:17,000
1,000 up to about 1951 finds most of the

419
00:17:19,870 --> 00:17:17,480
areas

420
00:17:21,280 --> 00:17:19,880
which you'd expect in other words both

421
00:17:22,990 --> 00:17:21,290
of them act roughly the same because

422
00:17:24,370 --> 00:17:23,000
they're not chemically active yet all

423
00:17:26,980 --> 00:17:24,380
which occurs at high temperature or

424
00:17:28,329 --> 00:17:26,990
disassociation occurs but if one zeroes

425
00:17:32,230 --> 00:17:28,339
in one finds that there is an active

426
00:17:34,330 --> 00:17:32,240
region roughly between 1700 and about

427
00:17:35,710 --> 00:17:34,340
1950 where one has a great deal of

428
00:17:37,720 --> 00:17:35,720
difference between the tungsten and

429
00:17:39,190 --> 00:17:37,730
rhenium the temperature difference

430
00:17:41,890 --> 00:17:39,200
between the tungsten rhenium under these

431
00:17:44,799 --> 00:17:41,900
circumstances is up to about over 125

432
00:17:47,380 --> 00:17:44,809
degrees Kelvin which is roughly about 6%

433
00:17:49,419 --> 00:17:47,390
of the 1950 which is the maximum

434
00:17:50,860 --> 00:17:49,429
temperature that would be equivalent to

435
00:17:53,230 --> 00:17:50,870
this glass of water

436
00:17:55,960 --> 00:17:53,240
chilling itself down by roughly 20

437
00:17:59,770 --> 00:17:55,970
degrees in this room so in relative

438
00:18:01,180 --> 00:17:59,780

temperature so in summary the filament

439
00:18:03,039 --> 00:18:01,190
experiments support the blackbody

440
00:18:04,299 --> 00:18:03,049
experiments and demonstrate that one can

441
00:18:06,100 --> 00:18:04,309
sustain a steady state temperature

442
00:18:09,990 --> 00:18:06,110
temperature differential under black

443
00:18:12,490 --> 00:18:10,000
body cavity conditions and the blackbody

444
00:18:15,190 --> 00:18:12,500
experiments confirmed Duncan's paradox

445
00:18:16,860 --> 00:18:15,200
and conflict with the second law random

446
00:18:20,680 --> 00:18:16,870
and systematic errors we're all

447
00:18:22,539 --> 00:18:20,690
acknowledged none can can account for

448
00:18:25,680 --> 00:18:22,549
these large temperature differentials or

449
00:18:27,909 --> 00:18:25,690
their sustained nature future directions

450
00:18:29,500 --> 00:18:27,919
our lab is now looking for room

451
00:18:30,880 --> 00:18:29,510
temperature analogues to this because

452
00:18:32,230 --> 00:18:30,890
once the room temperature analogues can

453
00:18:34,690 --> 00:18:32,240
be found commercial devices can be

454
00:18:36,940 --> 00:18:34,700
produced power densities for these are

455
00:18:38,890 --> 00:18:36,950
quite high power densities for the

456
00:18:40,450 --> 00:18:38,900
experiments just described are in the

457
00:18:43,000 --> 00:18:40,460
order of 50 kilowatts per square meter

458
00:18:44,500 --> 00:18:43,010
in terms of the power difference the

459
00:18:47,070 --> 00:18:44,510
energy difference power differences

460
00:18:49,180 --> 00:18:47,080
between the tungsten and rhenium

461
00:18:50,640 --> 00:18:49,190
surfaces this should be able to be

462
00:18:52,900 --> 00:18:50,650
scaled up by a factor of a thousand

463
00:18:55,720 --> 00:18:52,910

lastly we'd like very much to have

464
00:18:58,980 --> 00:18:55,730
replication experiments done of this so

465
00:19:04,030 --> 00:18:58,990
in conclusion theory indicates that

466
00:19:05,890 --> 00:19:04,040
based on multiple theory papers that the

467
00:19:08,080 --> 00:19:05,900
second law should be suspect at high

468
00:19:09,880 --> 00:19:08,090
temperature and in these kinds of

469
00:19:14,420 --> 00:19:09,890
reactions experiments have now shown

470
00:19:27,360 --> 00:19:14,430
this to be the case thank you

471
00:19:33,670 --> 00:19:30,580
would it be accurate to say that the

472
00:19:35,710 --> 00:19:33,680
reason this effect only appears in your

473
00:19:40,690 --> 00:19:35,720
experiments at high temperatures is

474
00:19:44,010 --> 00:19:40,700
because the dissociation energy of

475
00:19:46,570 --> 00:19:44,020
hydrogen is is high enough that the

476
00:19:48,520 --> 00:19:46,580
dissociation rate is negligible at lower

477
00:19:50,470 --> 00:19:48,530
temperatures which would seem to imply

478
00:19:53,230 --> 00:19:50,480
that if you want a room-temperature

479
00:19:55,200 --> 00:19:53,240
analogue you want to search for a gas

480
00:19:57,760 --> 00:19:55,210
species where the dissociation

481
00:20:00,640 --> 00:19:57,770
recombination energy is comparable to

482
00:20:02,170 --> 00:20:00,650
room temperature thermal energy yes

483
00:20:04,930 --> 00:20:02,180
that's exactly what I wanted to say I

484
00:20:06,790 --> 00:20:04,940
didn't have time so thank you York so

485
00:20:08,350 --> 00:20:06,800
yes the room temperature studies will be

486
00:20:10,890 --> 00:20:08,360
looking at molecules that aren't

487
00:20:13,810 --> 00:20:10,900
covalently bonded so for hydrogen the

488
00:20:15,910 --> 00:20:13,820

disassociation energy is about 4.5 evie

489
00:20:17,620 --> 00:20:15,920
and it works very well at around 2,000

490
00:20:19,390 --> 00:20:17,630
degrees and higher so for room

491
00:20:21,490 --> 00:20:19,400
temperature ones you would want to drop

492
00:20:24,040 --> 00:20:21,500
that bond energy by roughly a factor of

493
00:20:25,420 --> 00:20:24,050
five to ten and the type of bond that

494
00:20:28,060 --> 00:20:25,430
would be appropriate for that would be

495
00:20:30,100 --> 00:20:28,070
either van der Waals bonds or hydrogen

496
00:20:31,690 --> 00:20:30,110
bonds so the kinds of dimers were

497
00:20:35,050 --> 00:20:31,700
looking at now are things like formic

498
00:20:37,270 --> 00:20:35,060
acid and acetic acid which have hydrogen

499
00:20:39,370 --> 00:20:37,280
bonds exactly in that range so we will

500
00:20:42,720 --> 00:20:39,380
be looking at those particular molecules

501
00:20:44,710 --> 00:20:42,730
on room-temperature surfaces Thank You

502
00:20:46,660 --> 00:20:44,720
Bernie be fair to say that what you're

503
00:20:47,770 --> 00:20:46,670
doing altima is capturing maybe solar

504
00:20:49,270 --> 00:20:47,780
energy because everything in the

505
00:20:51,600 --> 00:20:49,280
environment has been heated by the Sun

506
00:20:53,680 --> 00:20:51,610
pretty much that's worthy all the

507
00:20:55,270 --> 00:20:53,690
environments come from so would you say

508
00:20:56,680 --> 00:20:55,280
it's all familiar just another indirect

509
00:20:57,700 --> 00:20:56,690
way of capturing solar energy well yeah

510
00:21:01,630 --> 00:20:57,710
you could say it came from the Big Bang

511
00:21:03,880 --> 00:21:01,640
if you want sure in terms of an ongoing

512
00:21:06,220 --> 00:21:03,890
heating process you're extracting this

513
00:21:08,110 --> 00:21:06,230

from the environment know the world of

514
00:21:09,400 --> 00:21:08,120
the world is mostly heated by the Sun I

515
00:21:11,980 --> 00:21:09,410
mean we have a little bit residual

516
00:21:13,300 --> 00:21:11,990
radioactivity from from the formation of

517
00:21:14,860 --> 00:21:13,310
the earth and and gravitational

518
00:21:16,450 --> 00:21:14,870
accretion accretion energy but yeah it's

519
00:21:18,850 --> 00:21:16,460
it's basically thermal but the

520
00:21:20,530 --> 00:21:18,860
difference is this now become if you can

521
00:21:22,930 --> 00:21:20,540
actually extract the energy from the

522
00:21:24,610 --> 00:21:22,940
environment it becomes recyclable in

523
00:21:25,870 --> 00:21:24,620
other words you don't have to pay for

524
00:21:27,820 --> 00:21:25,880
your energy anymore

525
00:21:30,130 --> 00:21:27,830
and the kinds of devices I'm talking

526
00:21:31,630 --> 00:21:30,140
about our devices which are sent as this

527
00:21:33,100 --> 00:21:31,640
piece of paper which sustained 100

528
00:21:35,410 --> 00:21:33,110
degree temperature differential across

529
00:21:37,000 --> 00:21:35,420
one side to the other in which case you

530
00:21:39,430 --> 00:21:37,010
can put plop this down into cold water

531
00:21:41,140 --> 00:21:39,440
and the other side will boil water for

532
00:21:44,110 --> 00:21:41,150
you and that energy comes directly from

533
00:21:46,480 --> 00:21:44,120
the environment so it is solar energy

534
00:21:50,080 --> 00:21:46,490
but it but it's but the difference is

535
00:21:51,610 --> 00:21:50,090
solar energy is used and then lost here

536
00:21:53,730 --> 00:21:51,620
the thermal energy is always around us

537
00:21:56,800 --> 00:21:53,740
and always will always be around us

538
00:21:59,170 --> 00:21:56,810

renewed by the Sun well in principle if

539
00:22:02,140 --> 00:21:59,180
you were to seal up this room completely

540
00:22:03,400 --> 00:22:02,150
in a perp in a perfect thermos you could

541
00:22:05,830 --> 00:22:03,410
run everything and it's in this room

542
00:22:07,150 --> 00:22:05,840
forever on its own thermal energy so

543
00:22:09,490 --> 00:22:07,160
that's a difference I mean you can

544
00:22:23,700 --> 00:22:09,500
decouple yourself from continuous use of

545
00:22:28,720 --> 00:22:27,310
it's Charles Daniel I read your paper as

546
00:22:29,770 --> 00:22:28,730
you know I commend you for your good

547
00:22:32,620 --> 00:22:29,780
work thank you

548
00:22:37,450 --> 00:22:32,630
hope this question makes sense did you

549
00:22:39,430 --> 00:22:37,460
run a total thermal dissipation budget

550
00:22:41,380 --> 00:22:39,440
and did that include the ohmic heating

551
00:22:43,480 --> 00:22:41,390
in the filaments no it's a good point

552
00:22:44,799 --> 00:22:43,490
the reason why the particular

553
00:22:46,600 --> 00:22:44,809
experiments here we'll never have any

554
00:22:49,000 --> 00:22:46,610
commercial application is because you

555
00:22:50,230 --> 00:22:49,010
have to heat the system up to over 1500

556
00:22:52,810 --> 00:22:50,240
degrees before you start seeing the

557
00:22:53,919 --> 00:22:52,820
effect and so when you actually look at

558
00:22:55,510 --> 00:22:53,929
the amount of energy that goes into the

559
00:22:57,400 --> 00:22:55,520
vacuum pumps into the ohmic heating of

560
00:22:59,320 --> 00:22:57,410
the blackbody and so on you're not this

561
00:23:01,390 --> 00:22:59,330
is not commercially viable that's most

562
00:23:03,490 --> 00:23:01,400
certainly true but the principle has

563
00:23:05,380 --> 00:23:03,500

been made the second law is supposed to

564
00:23:07,419 --> 00:23:05,390
apply for absolute zero to infinite

565
00:23:10,180 --> 00:23:07,429
temperature and so if you can prove it

566
00:23:12,400 --> 00:23:10,190
in any temperature regime the second law

567
00:23:14,350 --> 00:23:12,410
is no longer absolute and that opens the

568
00:23:15,880 --> 00:23:14,360
door for other possibilities and so our

569
00:23:18,580 --> 00:23:15,890
what we're trying to do is bring it down

570
00:23:20,919 --> 00:23:18,590
from 2,000 degrees this effect down by a

571
00:23:23,230 --> 00:23:20,929
factor of six roughly to rim temperature

572
00:23:25,600 --> 00:23:23,240
and then we can make devices like I'm

573
00:23:27,990 --> 00:23:25,610
describing with like I'm describing so

574
00:23:30,190 --> 00:23:28,000
in terms of energy budget we don't claim

575
00:23:32,350 --> 00:23:30,200
we claim that we have demonstrated the

576
00:23:37,440 --> 00:23:32,360
breakdown in the second law but not a

577
00:23:41,920 --> 00:23:37,450
commercially viable one thank you

578
00:23:47,769 --> 00:23:41,930
[Applause]