FIRE AND INCANDESCENCE IN HALAKHAH

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Introduction

Fire is of significance in many areas of *halakhah*. Three of the primary categories of work forbidden on Sabbath—cooking, kindling, and extinguishing—all require fire, and when the Sabbath leaves us, we pronounce a blessing over fire. Also, a number of commandments connected with the Sanctuary and the courts require fire. Therefore, an accurate definition of fire is an important question in *halakhah*. It is also a rather intricate question, requiring the analysis of many Talmudic passages. The reader is referred to another paper[1] where the *halakhic* aspects are treated in detail. Here we present only a summary of the conclusions and concentrate on the physical questions involved. These turn out to be non-trivial. Incandescence plays an important role here—and is a rather difficult state to determine thermometrically. The temperatures required for the heat-treatment of steel, too, are significant in connection with "kindling" and "extinguishing" on the Sabbath. Both of these questions are treated here.

Fire as a source of damage, too, is an important topic in *halakhah*; but this is outside the scope of this paper.

Halakhic Summary

GENERAL

There are essentially four characteristics commonly associated with fire. They are:

1. Production of heat
2. Production of light

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3. Production of a flame
4. Consumption of fuel

A passage in Tractate Pesachim[2] establishes that a glowing coal is legally fire, so that flame production is clearly not a condition. It is also widely accepted[3-10] that a glowing metal is fire, so that according to these opinions fuel consumption is not a condition. This leaves heat and light production as conditions of fire.

Halakhah also establishes a distinction between fire itself and heat resulting from fire (*toladoth esh*): in some cases fire itself is required and, in others, heat resulting from fire suffices.

One difficulty results from the *halakhic* ruling that the sun is not considered fire[11] and hot springs are not hot as a result of fire[11a 12 2].

Since the sun produces both heat and light, it should, according to the above criterion, be considered fire. Similarly, hot springs should be considered *toladoth esh*, assuming that their heat is derived—even if only indirectly—from incandescent lava. That they are not considered fire at all poses a *halakhic* problem which does not yet seem to have been resolved [1a].

On the basis of a classical commentary[11b], it has been suggested[12a] that only in connection with Sabbath work, which requires "appropriate techniques" (*melekheth mach'sheveth*) is the sun considered not to be fire. However, this suggestion is contradicted by the corresponding Talmudic wording, which is perfectly general. Furthermore, since the sun is not considered to be fire in connection with the Pessach-sacrifice, the cooking of meat with milk, the execution by burning[2], and originating a fire on *Yom Tov* (cf. end of this section), this position seems to be untenable.

The physicist might note that both the sun and the earth's core are fueled by nuclear processes and conclude that heat resulting from such processes is not considered fire, though there does not seem to be any obvious reason for this.

We now summarize the major *halakhoth* concerning fire.

The following require actual fire - including glowing coals and, possibly, glowing metal:

1. Roasting the Pessach sacrifice[2]
2. Burning the "inner" sin-offering[2]
3. Prohibition against extinguishing the fire of the altar[13]
4. The blessing on fire at the conclusion of the Sabbath[14]
5. The creation of a fire only from an existing fire on Yom Tov[15] (According to one authority[16] this belongs in the next category).

For the following, heat resulting from fire suffices—but heat from a source other than fire does not suffice.

1. Execution of a criminal whose punishment is burning[2]

2. The burn on which there has developed *tzara'ath* (a skin condition entailing ritual impurity)[2]

3. The definition of cooking, baking, roasting, etc. This is of significance in connection with the forbidden Sabbath-work category,[11] with the prohibited eating of the Passover sacrifice that was cooked,[12] and, probably, with the prohibited cooking of meat with milk[17] and the definition of "bread" as regards the obligation to separate *challah*.[18]

KINDLING AND EXTINGUISHING

Making a fire on the Sabbath is forbidden as kindling.[19] In addition, Rambam rules that anyone heating iron in order to harden it (by quenching) in water is guilty of Sabbath work in a category subsidiary (*toladah*) to kindling.[20] He then explains[21] that it is part of the usual practice of iron workers to heat iron until "it becomes a coal" and then to quench it in water to harden it.

The question here is whether the heating must be sufficient to cause incandescence, as implied by the expression "becoming coal".

In another passage,[22] Rambam rules that, on heating metal "until it becomes a coal" (presumably that is until it glows) one is guilty of work in a category derivative to cooking. It seems that only heating for purposes of hardening falls under the category of kindling.[23-27]

Concerning extinguishing, the Talmud[28] tells us in conjunction with the many ablutions of the High Priest on Yom Kippur, that they heated chunks of iron from before Yom Kippur to put into the water used for the ablutions on Yom Kippur in order to remove the chill. To the question that this involves hardening (the iron) on Yom Kippur, the Talmud replies that here the hardening is unintentional and therefore permissible in the Sanctuary where Rabbinic decrees did not apply.

Rambam rules,[21] apparently on the basis of this passage, that quenching a "metal coal" is only Rabbinically prohibited; but anyone doing it with intent to harden, is guilty of Sabbath work of a category derivative of extinguishing.

The fact that Rambam classifies heating and cooling hot iron as derivative of kindling and extinguishing only when the intent is to harden seems to contradict the assumption that hot metal is fire. The relationship between these actions and kindling and extinguishing must be sought in the basic purposes of these work categories. The basic purpose of extinguishing is widely accepted as being part of the charcoal manufacturing process.[29-31] The basic purpose of kindling is subject to differences of opinion, but there are indications that here, too, changing the state of the material is the basic purpose: basic kindling is for producing charcoal or ashes.[1b]

Cooking, too, has as its basic purpose the changing of the state of the object by heating; but, whereas cooking brings about the change directly, kindling is only the first step in a two-step process. From this point of view, we can readily understand how heating and quenching for hardening purposes are fully analogous to kindling and extinguishing. On the other hand, since they are similar only in purpose (and not in the form of the action), they are only *toladoth* and, since the similarity resides only in the purpose of the action, once this is missing, there is no more similarity at all, and the action ceases to be Sabbath work.[1c]

In another passage, the Talmud[32] states that (in order to avoid injury to passersby) it is permissible to extinguish a "metal coal" lying in a public thoroughfare, but not a "wooden coal". According to Rashi,[30] this is because the work of extinguishing *per se* is essentially the production of charcoal and this does not apply to a "metal coal." The *Gaonim* (*Halakhoth Gedoloth,*[33] Rav Hai,[34] and Rabbenu Chananel[35]) explain the distinction on the grounds that the "wooden coal" is not so dangerous; as long as it is potentially harmful, it exhibits a visible glow, whereas the "metal coal" continues to be harmful after it has ceased to glow.

This latter explanation seems to imply that the prohibition against quenching a "metal coal" applies also to hot metal at a temperature below incandescence. This interpretation is, however, far from certain.[36] Furthermore, as we show in the next section, a metal will glow visibly in the dark at temperatures far below those causing a glow noticeable under daylight conditions, so that a piece of incandescent metal may not be recognizable as such outdoors.

KOSHERING UTENSILS

According to Torah law[37 38] a vessel that has been used with non-kosher food, on a fire (other than in cooking, which limits the temperature to about 100°C) can be used with kosher food only after it has "passed through fire". According to *halakhah* it must be heated until "a layer peels off"[39] or until "sparks jump off it."[40 38] Practice seems to agree that bringing the utensil to incandescence suffices.[41] This is justified on the ground that the purpose is to burn the absorbed food particles[42] and to this end it suffices if the utensil itself turns into fire.

Koshering utensils is thus another case where incandescence is significant in *halakhah*.

SUMMARY

Let us summarize the above analysis in terms of temperature requirements:

For all the laws requiring fire, the substances must attain incandescence (if indeed, incandescent substances qualify as fire). According to *halakhic* practice, this includes koshering utensils used in fire.

When actual fire is required, the substance itself must attain this temperature; when fire derivative suffices, the original source of the heat must have attained that temperature.

The transgressions of the Sabbath work prohibitions derived from kindling and extinguishing require heating iron to a temperature which prepares it for hardening by quenching - independent of incandescence.

Let us now determine the required temperatures in thermometric terms.

Temperature determination

INCANDESCENCE

The temperature at which a body becomes incandescent to a degree noticeable to a normal observer depends on a number of parameters. We now list the most important of these, together with a brief discussion of each.

1. *Surface emissivity*. The radiance of a blackbody is given by Planck's radiation formula directly. The term "blackbody" implies full absorption of all incident radiation. This is thermodynamically equivalent to full emissivity.

Real bodies are not totally "black" in this sense, and hence their radiance at a given temperature is lower than that of a blackbody by a factor equal to the absorptivity (i.e. emissivity). For stainless steel and tungsten, for instance, this has been measured as 0.35[43] and 0.45[44] respectively.

2. *Luminance of environment*. Differences in luminances between adjacent area elements are detected very much more readily than absolute changes in luminance. Also, the detectable difference tends to be proportional to the background luminance level (Weber's Law).

The smallest amount of detectable luminance will be detectable in a totally dark environment. In detecting incandescence under conditions of substantial illumination, in the absence of a comparison field, it will be the change in color (reddening) of the incandescent body which first becomes noticeable.

3. *Dark adaptation*. When an observer enters a dark environment after being exposed to higher light levels, his ability to detect low luminance values continues to improve - first rapidly, later more slowly - until he attains his maximum sensitivity after about an hour in total darkness.[45] This state is called full dark adaptation.

4. *Object size*. The visual apparatus has some type of integration capability operating over relatively large angles, so that the threshold

luminance drops as the object size increases. (It is the retinal image size which is significant here; this, in turn, is proportional to the angular object size).

5. *Detection criterion.* The classical concept of "threshold" (below which the signal has no effect) has now been replaced by the concept of noise level. According to this modern concept, there is no absolute threshold. Rather, as the signal level rises, the probability of detection increases.[46] Often, a 50% detection probability is taken as the threshold.

It is clearly impractical to calculate temperature values for all possible combinations of the above parameters.

In Table 2 we give the threshold temperature for visible incandescence under conditions of total darkness and full dark adaptation, for various object sizes and emissivities. These are based on Blackwell's[47] values of threshold luminance and on the values of blackbody scotopic luminance as a function of temperature as listed in Table 1* and Reference 50. Threshold is defined as under 5. above.

The temperature values given in Table 2 should therefore represent a lower limit.

To properly evaluate the Talmudic passage[32] of quenching the "metal coal" on a public thoroughfare, it is important to know at what temperature incandescence becomes noticeable under daylight illumination. As noted earlier this occurs when the change of hue toward the red becomes noticeable.**

In Table 3, we list the temperatures under which the incandescence equals the reflected ambient luminance value (p = 0.5), half this luminance value (p = 0.33), and one quarter thereof (p = 0.2). We do this for reflectance values (r) of 0.5, 0.6, and 0.7. The appropriate formula in terms of the corresponding incandescence luminescence (L_i) is readily seen to be:

* These values were obtained by a numerical integration process described in Reference 48. The data of Table 2, too, were published there.

**Here we may take the ratio of the incandescence luminance to the total luminance (reflected ambient plus incandescent) as a measure of color purity, even though that is strictly valid only when the incandescent radiation is metameric with pure monochromatic radiation. We justify this because:

(1) At the start of incandescence, the visible portion of the spectrum is restricted to the red end of the spectrum,

(2) There the hue changes but slowly with wavelength, and

(3) There the spectral colors are confined to a portion of the color triangle border which is almost completely linear, so that the color of incandescence, too, lies on the border of the color triangle.

Under laboratory conditions, and when two different fields - each perfectly uniform - are placed adjacent to each other, an addition of about 5% of red (0.65 μm) radiation produces a barely noticeable shift toward the red.[49] However, under field conditions, and on an absolute basis, the amount of required red radiation will be substantially more.

$$p = \frac{L_i}{L_i + L_r} = \frac{(1 - r) L_B}{(1 - r) L_B + rE_A/\pi}$$

Where p is the fraction of the total luminescence contributed by incandescence.

L_r is the luminescence contributed by reflection of the ambient illumination. E_A.

L_B is the blackbody luminance of incandescence observed at the same temperature. and we have assumed a Lambert-law reflector.

TEMPERATURE FOR HARDENING

Steel can take various crystalline forms, which differ significantly in their hardness. The hardening process involves heating steel to a critical temperature at which it takes the austenite form. When the steel is then permitted to cool slowly from this temperature, it converts into the relatively soft pearlite form. If it is cooled sufficiently rapidly (ca.1 sec.) to below another critical temperature, it turns into the very hard martensite form. The amount of hardening obtainable and the values of the critical temperatures depend on the composition of the steel, especially on its carbon content. It would appear[54] that practically all commercial steels require heating to at least 1000°K for complete hardening. At this temperature, the luminance of the incandescence of the steel is about 1 nit and the incandescence is readily detectable under subdued lighting. It would not, however, be detectable outdoors during daytime.

Summary

It was established that the determination of the temperatures required for incandescence and heat-treatment of steel is significant in *halakhic* decisions. This determination was then treated quantitatively.

TABLE 1

Luminance of Blackbody Radiator (scot. cd/m^2)

Temp (°K)	0	10	20	30	40	50	60	70	80	90	Exp
600	0.741	1.43	2.70	5.00	9.12	16.3	28.8	50.0	85.5	144	$\times 10^{-7}$
700	0.239	0.392	0.635	1.02	1.60	2.51	3.87	5.92	8.96	13.4	$\times 10^{-4}$
800	1.99	2.93	4.27	6.18	8.85	12.6	17.8	24.9	34.6	47.7	$\times 10^{-3}$
900	6.55	8.92	12.1	16.2	21.7	28.9	38.2	50.2	65.6	85.2	$\times 10^{-2}$

TABLE 2*
Temperatures for Threshold Visibility

TARGET DIAM (mrd)	L ($\mu cd/m^2$)	T(1) (°K)	T(0.5) (°K)	T(0.4) (°K)	T(0.3) (°K)
1.047	1884	798	816	822	830
2.82	224	747	763	768	772
5.29	87.3	725	742	746	753
16.06	12.3	686	700	705	711
35.2	5.0	670	682	687	692
803**	0.75	636	648	653	657

TABLE 3
Temperatures for Threshold Outdoors Incandescence

Solar † Elevation (°)	Illum.*** (lm/m^2)	p = 0.5			p = 0.33			p = 0.2		
		T(0.5)	T(0.4)	T(0.3)	T(0.5)	T(0.4	T(0.3)	T(0.5)	T(0.4	T(0.3)
90	124,000	1645	1691	1745	1569	1612	1662	1503	1540	1585
50	85,000	1601	1647	1699	1532	1571	1620	1468	1505	1547
30	47,000	1540	1583	1630	1478	1515	1556	1416	1452	1491
10	10,900	1410	1445	1484	1353	1385	1423	1303	1331	1364
5	4,760	1342	1374	1311	1293	1323	1354	1246	1274	1304
0	732	1215	1241	1271	1172	1197	1225	1134	1155	1181
−0.8	453	1185	1210	1235	1145	1168	1193	1107	1130	1153
−5	10.8	997	1013	1034	972	984	1003	941	956	974
−6	3.4	950	966	984	923	938	956	898	912	929
−12	.0083	808	818	830	790	800	811	773	782	793
−18	.00065	746	755	765	730	739	750	715	724	733

† Elevation angles − 0.8°, − 6°, − 18° correspond approximately to halakhic sunset, night-fall (Rav of Ladi), and night-fall (Rabbenu Tam), resp. Cf. Ref. 51.

Elevation angles − 6°, − 12°, − 18° are end of civil, nautical, and astro nomical twilight, resp.

* The arguments of T are emissivity values: $\varepsilon = 1 - r$

** Based on Ref. 52

*** Based on Ref. 53

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